THIRTY-NINTH ANNUAL REPORT

OF THE

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

1953

INCLUDING TECHNICAL REPORTS
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To the Congress of the United States:

In compliance with the provisions of the act of March 3, 1915, as amended, establishing the National Advisory Committee for Aeronautics, I transmit herewith the Thirty-ninth Annual Report of the Committee covering the fiscal year 1953.

DWIGHT D. EISENHOWER.

THE WHITE HOUSE,
JANUARY 25, 1954.

Letter of Submittal

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

WASHINGTON, D. C., *November 24, 1953.*

DEAR MR. PRESIDENT: In compliance with the act of Congress approved March 3, 1915, as amended (U. S. C. title 50, sec. 151), I have the honor to submit herewith the Thirty-ninth Annual Report of the National Advisory Committee for Aeronautics for 1953.

This has been an historic year in aeronautics. For the first time the prototype of a military service airplane, the Air Force North American F–100 Super Sabre, flew faster than sound in level or climbing flight. Heretofore such speed has been attained only with research aircraft. The F–100 is only the first of a series of supersonic aircraft scheduled for quantity production for the military services.

In 1953 man flew at twice the speed of sound for the first time. An NACA research pilot attained a speed of 1327 miles per hour in a research airplane, the Navy Douglas D–558–II Skyrocket. This Navy plane was part of the same long-range program that produced the Air Force Bell X–1, which 6 years ago first flew at supersonic speed.

These achievements climaxing the history of the first fifty years of powered flight are tangible evidence of teamwork between science, military, and industry that promises continuing progress in American aviation. On the other hand, scientific problems associated with supersonic flight are increasing in number, complexity, and expense, and therefore many important problems cannot, within existing resources, be studied as intensively as they merit.

Respectfully submitted.

JEROME C. HUNSAKER,
Chairman.

THE PRESIDENT,
The White House, Washington, D. C.

National Advisory Committee for Aeronautics

Headquarters, 1724 F Street NW., Washington 25, D. C.

Created by act of Congress approved March 3, 1915, for the supervision and direction of the scientific study of the problems of flight (U. S. Code, title 50, sec. 151). Its membership was increased from 12 to 15 by act approved March 2, 1929, and to 17 by act approved May 25, 1948. The members are appointed by the President and serve as such without compensation.

JEROME C. HUNSAKER, Sc. D., Massachusetts Institute of Technology, *Chairman.*

DETLEV W. BRONK, PH. D., President, Rockefeller Institute for Medical Research, *Vice Chairman.*

HON. JOSEPH P. ADAMS, member, Civil Aeronautics Board.

ALLEN V. ASTIN, PH. D., Director, National Bureau of Standards.

LEONARD CARMICHAEL, PH. D., Secretary, Smithsonian Institution.

LAURENCE C. CRAIGIE, Lieutenant General, United States Air Force, Deputy Chief of Staff (Development).

JAMES H. DOOLITTLE, Sc. D., Vice President, Shell Oil Company.

LLOYD HARRISON, Rear Admiral, United States Navy, Deputy and Assistant Chief of the Bureau of Aeronautics.

RONALD M. HAZEN, B. S., Director of Engineering, Allison Division, General Motors Corporation.

WILLIAM LITTLEWOOD, M. E., Vice President, Engineering, American Airlines, Inc.

HON. ROBERT B. MURRAY, JR., Under Secretary of Commerce for Transportation.

RALPH A. OFSTIE, Vice Admiral, United States Navy, Deputy Chief of Naval Operations (Air).

DONALD L. PUTT, Lieutenant General, United States Air Force, Commander, Air Research and Development Command.

ARTHUR E. RAYMOND, Sc. D., Vice President, Engineering, Douglas Aircraft Company, Inc.

FRANCIS W. REICHELDERFER, Sc. D., Chief, United States Weather Bureau.

THEODORE P. WRIGHT, Sc. D., Vice President for Research, Cornell University.

HUGH L. DRYDEN, PH. D., *Director*
JOHN W. CROWLEY, JR., B. S., *Associate Director for Research*

JOHN F. VICTORY, LL. D., *Executive Secretary*
EDWARD H. CHAMBERLIN, *Executive Officer*

HENRY J. E. REID, D. ENG., Director, Langley Aeronautical Laboratory, Langley Field, Va.

SMITH J. DEFRANCE, D. ENG., Director, Ames Aeronautical Laboratory, Moffett Field, Calif.

EDWARD R. SHARP, Sc. D., Director, Lewis Flight Propulsion Laboratory, Cleveland Airport, Cleveland, Ohio.

THIRTY-NINTH ANNUAL REPORT

OF THE

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

WASHINGTON, D. C., *November 19, 1953.*

To the Congress of the United States:

This is the fiftieth year since Wilbur and Orville Wright at Kitty Hawk, N. C., made their first powered flight. That airplane was a fragile and unsteady machine of no immediate utility. It flew for only a minute but it disclosed the solution of the age-old problem of human flight.

The Wrights were the first in the history of man to fly. There was no one to teach them. They had to discover principles and to learn the art by cautious and methodical experimenting. From their own research they obtained the practical information needed to design their successful flying machine.

The Wrights received no effective aid from the theoretical studies of flight made by the mathematicians of the nineteenth century. The science of aerodynamics was developed in response to the practical demands of aeronautics in the years to follow.

In 1908, the Wrights demonstrated at Fort Myer, Va., a vastly improved flyer, the first military airplane. It carried a passenger and flew for more than an hour. Following this public demonstration, the development of the airplane was taken up vigorously. At first France and Germany took the lead, then Great Britain, but the United States lagged behind in the furthering of this greatest American development of the century.

With war clouds in view in 1915, the Congress established the National Advisory Committee for Aeronautics to undertake the scientific study of the problems of flight with a view to their practical solution. President Wilson appointed the members of the first Committee, consisting of the heads of the military and civil agencies of the Government concerned with aeronautics and experts from private life.

Over the succeeding 38 years, the Congress has annually appropriated funds in support of the Committee's research. During the period between the two World Wars, the Committee supplied scientific and engineering knowledge which contributed substantially to American leadership in aeronautics and victory in the air.

The Committee has functioned as a board of directors to plan as a body and supervise the execution of research programs conducted by a dedicated Civil Service staff of some 7,000 men and women. In this responsibility to the Nation, the Committee has had the assistance of 28 technical subcommittees recruited from governmental agencies, universities, manufacturers and the airlines. Coordination of the many interests concerned with research has been effectively accomplished within the Committee because of the interlocking character of its membership.

The intensity with which scientific research is pursued determines the rate at which new knowledge is acquired and consequently the rate of progress which can be made in improving the performance and efficiency of America's aircraft. Many problems of importance are known to exist, which cannot be studied as intensively as they merit within existing resources.

Before the end of the next fiscal year the first of the NACA Unitary Plan wind tunnels, for which the Congress appropriated $75,000,000, will come into use. The Unitary Plan Act assigns to NACA the additional task of operating very large transonic and supersonic wind tunnels to be available to industry for developmental testing of aircraft and missiles.

Both the offensive potential of our atomic weapons, and our defense against such weapons, depend in major part on superior aircraft and missiles. By virtue of an immense effort this country holds a current position of leadership in many areas in aeronautical science. But no complacency is justified in view of the high scientific and technical capabilities disclosed by Soviet progress, including that in nuclear weapons. It cannot be assumed that the Soviets will not likewise make the advances in aeronautical science which we ourselves know to be possible.

The Committee, therefore, urges that the existing and potential capacity of the National Advisory Committee for Aeronautics be fully and intensively utilized to advance the aeronautical arts and sciences, born 50 years ago with the Wright brothers' airplane, and that the Congress provide the necessary support for this policy.

Respectfully submitted.

JEROME C. HUNSAKER,
Chairman.

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Part I—TECHNICAL ACTIVITIES

THE NACA—WHAT IT IS AND HOW IT OPERATES

One of the most important functions of the National Advisory Committee for Aeronautics is that of coordinating the aeronautical research carried on in the United States. The makeup of both the Main Committee and the 28 technical subcommittees embraces the several military and civil government agencies concerned with aeronautics, and includes members from scientific institutions, and the aviation manufacturing and operating industries. Thus wasteful and costly duplication of research and development effort is avoided.

In the conduct of its business, which is scientific laboratory research in aeronautics, the NACA, since its establishment in 1915 by the Congress, has functioned to serve the needs of all departments of the Government. The 17 members of the Main Committee are appointed by and report to the President. Serving without pay, they operate like a board of directors, establishing policy and planning the research programs to be followed by the 7,000 civil-service personnel who make up the technical and administrative staff of the NACA.

The Committee is assisted in the determination and coordination of research programs by 5 major and 23 subordinate technical committees, with a total membership of more than 400. These men are selected because of their technical ability, experience, and recognized leadership in a special field. They also serve without compensation, in a personal and professional capacity. They provide material assistance in the consideration of problems related to their technological fields, review research in progress both at NACA laboratories and in other organizations, recommend research projects to be undertaken, and assist in the coordination of research programs.

Membership on the technical committees and subcommittees, as well as the Industry Consulting Committee, is listed in part II of this report, beginning on page 54.

Coordination of research is also accomplished through frequent discussions by NACA technical staff personnel, with the research organizations of the aircraft industry, educational and scientific institutions, and other aeronautical agencies. The NACA maintains a West Coast office to further liaison with the aeronautical research and engineering staffs of that geographical area.

During the 38 years since its organization as an independent Federal agency, the NACA has sought to assess the current status of development of aircraft, both civil and military; to anticipate the research needs of aeronautics; to develop the scientific staff and special research facilities required, and to acquire the needed information as rapidly as may be consistent with the national interest.

The NACA's research programs have had both the long-range, all-inclusive objective of acquiring the new scientific knowledge essential to assure American leadership in aeronautics, and the immediate objective of solving, as quickly as possible, the most pressing problems, thus to give effective support to the Nation's current aircraft construction program.

Most of the problems to be studied are assigned to NACA's research centers: the Langley Aeronautical Laboratory in Virginia, where research is conducted on aerodynamic, structures, hydrodynamic, and other problems; the Ames Aeronautical Laboratory in California, which concentrates on aerodynamic research, and the Lewis Flight Propulsion Laboratory in Ohio, which is concerned primarily with powerplant problems. Smaller NACA research installations are located at Wallops Island, off the Virginia Coast, where aerodynamic problems in the transonic and supersonic speed ranges are studied using rocket-powered models in free flight, and at Edwards Air Force Base, California, where specially designed, specially instrumented research aircraft are used in full-scale flight research on transonic and supersonic problems.

In its work, often with research tools requiring use of air under great pressure and high temperature, the NACA has had to maintain constant vigilence to assure maintenance of adequate safety for its employees. Evidence of the success of the NACA's continuing program of accident prevention was the receipt of two awards from the National Safety Council in 1953.

On August 6, 1953, the Langley Aeronautical Laboratory received the Council's highest award, the Award of Honor. This recognition of good safety was the result of the 3,300 employees at the laboratory having worked a total of 3,325,640 man-hours without a disabling injury, in the period November 8, 1952, to May 1, 1953. The Council's Award of Merit was presented to the Lewis Flight Propulsion Laboratory for its 2,400 employees having worked 1,167,588 man-hours without a disabling injury for the period February 17, 1953, to May 13, 1953.

The NACA also sponsors and finances a coordinated program of research at 20 nonprofit scientific and educational institutions, including the National Bureau of Standards and the Forest Products Laboratory. By this means, scientists and research engineers, whose skills and talents otherwise might not be available, contribute importantly to the Government's program of aeronautical research. Promising students also receive scientific traning which makes them useful additions to the country's supply of technical manpower.

During the fiscal year 1953, the following institutions participated in the NACA's program of contract research:

National Bureau of Standards
Forest Products Laboratory
Battelle Memorial Institute
Polytechnic Institute of Brooklyn
California Institute of Technology
University of California
University of California at Los Angeles
Carnegie Institute of Technology
Case Institute of Technology
University of Chicago (NORC)
University of Cincinnati
Columbia University
Cornell University
University of Florida
Georgia Institute of Technology
Iowa State College
Johns Hopkins University
Massachusetts Institute of Technology
University of Michigan
University of Minnesota
Pennsylvania State College
University of Pittsburgh
Purdue University
Syracuse University
University of Wisconsin

Proposals from such institutions are carefully screened to assure best use of the limited funds available to the NACA for sponsoring research outside its own facilities. Similarly, results from these projects are reviewed to maintain the quality of this part of the NACA program. Reports of the useful results are given the same wide distribution as other NACA publications.

During the fiscal year, most of the NACA technical subcommittees reviewed proposals for research projects from outside organizations, or gave attention to reports from completed contracts. Reports covering results of sponsored research totaled 62 during fiscal year 1953.

Research information, including that obtained in the Committee's laboratories and elsewhere under NACA sponsorship, is distributed in the form of Committee publications. Reports and technical notes, containing information that is not classified for reasons of military security, are available to the public in general. Translations of important foreign research information are published as technical memorandums.

The NACA also prepares a large number of reports containing information of classified nature. These, for reasons of national security, are closely controlled as to circulation. When it is found possible at a later date to declassify such information, these reports also may be given wider distribution.

Current announcement of NACA publications is contained in the NACA Research Abstracts. This service, in addition to telling of NACA publications, makes note of important research reports received from abroad.

In addition to other means of research information readily available, the NACA each year holds a number of technical conferences with representatives of the aviation industry, universities, and the military services. Attendance at these meetings is restricted, because of the security classification of the material presented, and the subject material is focused upon a specific field of interest. During the fiscal year 1953, two such technical conferences were held.

UNITARY WIND TUNNELS

During 1953 the prototype of the USAF F–100 Super Sabre fighter, designed and manufactured by North American Aviation, Inc., made its first flight. It since has repeatedly reached supersonic speeds in level or climbing flight.

Accomplishment of faster-than-sound velocities by an airplane now in production and soon to be assigned to tactical units of the Air Force, underlines the great progress made in aeronautics during the past decade. Widely published predictions that tomorrow's tactical airplanes will fly at least twice as fast (a speed already attained by special research aircraft) seldom attempt to detail the problems which first must be solved, or to recount the vigorous steps being taken to conquer those problems.

It is hardly 10 years since Germany was preparing to make use of four radically new weapons of war, the V–1 buzz bomb, the supersonic V–2 guided missile, the Messerschmitt 262 jet fighter, and the Messerschmitt 163 rocket interceptor. It is less than 10 years since the United States began planning the postwar steps which would be required, by way of research and development, to insure fullest exploitation of the military possibilities of supersonic aircraft and missiles.

In the immediate postwar period it became apparent that there would be required a large national investment in wind tunnel equipment to enable attaining, and maintaining, the degree of technical supremacy in aeronautics which was felt imperative. The problem was given careful and detailed consideration by the Department of Defense, the NACA, representatives of the aviation industry, and others, and a master plan was prepared to provide America's wind tunnel needs.

From those studies, beginning in 1944 and continuing into 1947, several important conclusions were reached, in addition to formulation of the master plan covering wind tunnel needs. Among these were the following:

(1) Farsighted congressional support, during the decade prior to America's entry into World War II, had enabled construction by the NACA of large high-speed, though still subsonic, wind tunnels. It was felt they would be substantially adequate for anticipated research requirements in this speed range.

(2) In the past the needs of the aircraft industry for wind tunnel facilities in which to conduct development and evaluation work had been largely satisfied by the availability of such facilities at their own plants, at educational institutions, and elsewhere.

(3) Prior to World War II, a fund of basic aeronautical information had been gathered in the United States, by the NACA and educational institutions. This information was in advance of aviation practice, and could be drawn upon by the industry. By the end of the war, the fund of aeronautical information was seriously depleted; practice was running dangerously close to the forward limits of basic knowledge.

(4) Large wind tunnels and other facilities essential for development and evaluation work in the transonic and supersonic speed ranges would be so costly as to make it impossible for the industry to acquire such equipment for its use. The cost of a single supersonic tunnel large enough for development and evaluation work was calculated to be from $20,000,000 to $40,000,000 each. The alternative was to provide centralized Government facilities.

In April 1946 it was agreed that the plans being promulgated by the several agencies studying America's wind tunnel needs should be assessed comprehensively, thus to eliminate nonessential facilities as well as to guard against costly duplication. The task was undertaken by a Special Panel on Supersonic Laboratory Facilities, with NACA member Arthur E. Raymond the chairman, and composed of representatives from the Army Air Corps, the Navy, the Joint Chiefs of Staff Guided Missiles Committee, the aircraft industry, the aircraft engine manufacturers, and the NACA.

The recommendations of this group, known as the Raymond Panel, were in the form of a coordinated plan for wind tunnel procurement to accommodate the requirements of the agencies and the industry which shared responsibility in the task of attaining for the United States technical supremacy in aeronautics. The estimated cost of the facilities involved was $2,200,000,000, roughly the cost of the A-bomb.

During this period, Dr. Vannevar Bush, then a member of the NACA, used the word "unitary" in describing the national scope of the proposals. His phrasing characterized the unified approach taken to acquire a mature and informed assessment of the wind tunnel needs of the United States, and as the studies continued, the name "Unitary Wind Tunnel Plan" was adopted.

Realistic as had been the $2,200,000,000 procurement program proposed by the Raymond Panel, it was apparent that drastic downward revision of the total cost was imperative. In June 1946, the NACA established a Special Committee on Supersonic Facilities, with Dr. J. C. Hunsaker the chairman. The report of this committee, made the following January, proposed an integrated program of transonic and supersonic wind tunnel construction which would provide the facilities needed for both basic research and for development and evaluation work. With the necessary service facilities, the technical tools were estimated to cost $1,063,000,000, approximately one-half the original amount.

"When, if ever, new aircraft and missiles need to be provided in great quantity, cannot be determined now, yet their design cannot be improvised when needed," the committee observed. "We do know that the art is not stationary and that immense advantages in effectiveness are possible by practical applications of now predictable advances in aeronautical science. It is proposed, in essence, that the United States proceed to discover and make practical application of the possible advances in aeronautical science, and, by so doing, maintain its position of leadership in the air."

The basic Unitary Plan, as drafted by the special committee, included 16 small tunnels to be constructed at universities. These tunnels, it was proposed, would be used in providing better training of graduate students in supersonic aerodynamics. The plan also listed new tunnels to be built at existing NACA laboratories and at a Navy facility as electric power requirements permitted. To provide the largest of the new tunnels, the plan proposed creation of a National Supersonic Research Center, to be operated by the NACA, and a new Air Force establishment for the largest of the development and evaluation facilities. The two new research centers were to be located at sites where the great quantities of electric power needed in operation of the tunnels would be available.

Following adoption by the NACA, early in 1947, of the report of its special committee, the proposals were forwarded to the National Military Establishment for consideration by what was then the Joint Research and Development Board. This action was taken so that, following concurrence, the Unitary Plan could be presented to the Congress jointly by the military services and the NACA. For practical reasons, still further reduction in the recommendations followed, resulting in agreement upon a minimum program, involving appropriations over a 5-year period which totaled about $600,000,000.

On October 14, 1947, the Bell X-1 was piloted by then Capt. Charles E. Yeager, USAF, on a flight that attained supersonic speed. The airplane, one of several specially designed research aircraft, was the product of a joint undertaking in which the military services, the aircraft industry and the NACA were partners. The fact that, for the first time, supersonic speed had been achieved in level or climbing flight was the more impressive because the airplane's design features were, basically, so conventional. If anything, the speed of this remarkable airplane brought into sharper focus the urgent need for the facilities envisioned by the Unitary Plan.

The Unitary Plan was studied by the President's Air Policy Board which, in its report to the President, January 1, 1948, concluded ". . . the United States is dangerously short of equipment for research in the transonic and supersonic speed ranges. This deficiency should be remedied as quickly as possible. We recommend that the 16 supersonic tunnels projected for the universities be authorized and installed as quickly as possible . . . We recommend also that we proceed without delay in supplementing existing laboratory equipment with the new tunnels projected under the Unitary Plan in whatever order of priority and at whatever rate as will be recommended by the Research and Development Board."

March 1, 1948, the Congressional Aviation Policy Board, in its report, made the following recommendation concerning the Unitary Plan: "Physical facilities required for transonic and supersonic research and development of aircraft and guided missiles are so expensive they can be furnished only by Government. The NACA and the Research and Development Board are preparing a coordinated program of facilities required in the national interest. Since adequate research and development facilities are essential for continued United States aviation leadership, this plan should be expedited."

A month later, in April, the Secretary of Defense and the Chairman of the NACA forwarded jointly to the Bureau of the Budget for approval a draft of proposed legislation to authorize the Unitary Plan. Supplemental appropriation estimates to finance initial phases of the program were also presented.

Following approval by the Bureau of the Budget, the proposed Unitary Plan legislation was submitted, in March of 1949, to the 81st Congress. After House and Senate Committee hearings, followed by a Joint Conference Committee study, the final version passed both House and Senate on October 19. The Joint Bill was signed by the President October 27, 1949, and became Public Law 415, 81st Congress.

Composed of two parts, Public Law 415 authorized appropriation of $253,000,000 for construction of transonic and supersonic facilities. Of this amount, $10,000,000 was for tunnels at educational institutions, $136,000,000 was for six large tunnels at the NACA Laboratories, $7,000,000 was for a single tunnel to be operated by the Navy, and $100,000,000 was for establishment by the Air Force of its Air Engineering Development Center, at which would be located two propulsion facilities and a gas dynamics laboratory.

The Deficiency Appropriation Act of 1950, approved June 29 of that year, included $75,000,000 for construction of three Unitary Plan supersonic tunnels at the NACA laboratories: a 10-foot tunnel for engine work at the Lewis Flight Propulsion Laboratory, an 8-foot tunnel for aerodynamic investigations at the Ames Aeronautical Laboratory, and a 4-foot tunnel, also for aerodynamic investigations, at the Langley Aeronautical Laboratory. No funds were appropriated for supersonic tunnels at universities.

Initial appropriations for the facility to be operated by the Air Force, located at Tullahoma, Tenn., and now named the Arnold Engineering Development Center, totaled $157,500,000. Additional funds have since been authorized, bringing the total nearly to $170,000,000.

When in 1944 the planning began which would result in the Unitary Wind Tunnel Plan the maximum speed of airplanes was slightly over 500 miles an hour. To talk, at that time, about speeds of 1,300 or 1,400 miles an hour seemed but wishful thinking.

On November 20, 1953, NACA Research Pilot Scott Crossfield, in another of the special research airplanes, the D–558–II which Douglas had constructed under Navy contract and with NACA cooperation, flew twice the speed of sound (1327 mph at the altitude and temperature at which he was flying). As early as August, 1951, Douglas Pilot William Bridgeman had flown the Skyrocket 1238 mph. On these flights, as in the case of the Bell X–1, the research airplane was lifted to about 30,000 feet by a "mother plane" and then released to make its flight. The maximum speed was maintained for only a few seconds; the duration of the rocket engine was less than 5 minutes.

The importance of detailed transonic and supersonic experimentation, possible only under the controlled conditions of the laboratories, was not decreased by the progress made with the research airplanes; rather, it was increased as attention was focused more sharply upon the essentiality of learning how to keep aerodynamic drag as low as possible, thus to obtain maximum speed with the power plants available.

This, of course, is a problem that has been basic since the advent of the airplane, but today the possible gains, or losses, can be multiplied many times. In the past, the difference between an optimum design and one second best, might at most be only a few miles an hour. Today, the difference may be measured, literally, in hundreds of miles an hour. The "right" design may achieve the supersonic speed desired; the "wrong" design may be unable to attain higher than subsonic speeds.

The lack of mathematical methods for predicting theoretically aerodynamic behavior in the speed ranges of tomorrow's aircraft means that this kind of information must be obtained through use of experimental techniques, the most satisfactory of which requires use of the large wind tunnel of the kind being provided under the Unitary Wind Tunnel Plan.

Before the end of 1954, the first of the Unitary Plan supersonic wind tunnels will be in fruitful use as a tool in the hands of America's producers of supersonic aircraft and missiles. The planning of a decade ago began not a moment too soon.

AERODYNAMICS

The laboratories of the NACA have continued their basic and applied research programs in the field of aerodynamics to assist in the understanding of phenomena that affect the performance, stability, and control of current aircraft designs as well as to explore problems that will be faced by future designs. In addition to these efforts, test programs associated with the development of specific aircraft have been undertaken at the request of the military services. These studies have served to broaden the base of design knowledge throughout present and anticipated operating ranges of aircraft. The data have been obtained through the use of various analytical as well as experimental techniques. In many cases, special research equipment was utilized; for example, automatic computers and simulators, transonic, supersonic, and hypersonic wind tunnels, free-flight rocket and drop-body models, and full-scale research airplanes. Such problems as drag and control effectiveness at transonic and supersonic speeds, airplane tracking control, and automatic interception systems have been under intensive study.

The Committee on Aerodynamics and its subcommittees on Fluid Mechanics, High-Speed Aerodynamics, Stability and Control, Internal Flow, Propellers for Aircraft, Seaplanes, and Helicopters have continued to give guidance to the broad programs of the NACA laboratories in the aerodynamics field. This past year a special Conference on Aerodynamics of High-Speed Aircraft was held at the Ames Laboratory to assist in the early dissemination of NACA research data. The conference was attended by many representatives of the armed services and their major contractors. Their comments indicated high continued interest in this method of presenting pertinent new research information to the users.

The following paragraphs briefly describe many of the unclassified studies conducted by the NACA in the aerodynamics field during the past year.

FLUID MECHANICS

Theoretical Aerodynamics and Gas Dynamics

A method for determining the surface pressures for a family of two-dimensional airfoils in a sonic or supersonic stream has been developed. The method depends upon knowing the pressures of one member of the airfoil family. This technique is described in Technical Note 2910. For engineering purposes, this technique, an application of the method of characteristics, may be replaced by a simple application of Prandtl-Meyer flow concepts. An explanation of the nonlinear force characteristics of two-dimensional airfoils at transonic speeds is presented on the basis of sensitivity of these flows to changes in airfoil geometry and angle of attack

Some exact solutions of two-dimensional flows of compressible fluid have been obtained at the Johns Hopkins University under NACA sponsorship, and reported in Technical Note 2885. In this technical note a suggestion is given for classifying certain types of compressible flows. This seems to offer a convenient criterion for systematic investigation of these flows by Chaplygin's original method. The object of the paper is to present and analyze a few useful solutions of compressible potential flow with the exact gas law. These solutions include flows about convex corners and the exact solution of compressible flow through a particular contracting channel.

Several aspects of transonic flow around the forward portions of wedge profiles have been studied by means of interferometry. Measurements were made of the two kinds of flow patterns that occur at the leading edge of a wedge at an angle of attack. The growth of the supersonic region about a sharp convex corner formed by two flat surfaces was also observed. The results reported in Technical Note 2829 show the drag of a wedge of 14.5° semiangle at high subsonic Mach numbers to be consistent with that of wedges of smaller angle when plotted according to the transonic similarity law. It is demonstrated that part of the flow field around a hexagon and the wedge could be calculated rather accurately by the method of characteristics.

The effect of the blunt trailing edge on the pressure drag of rectangular and delta wings with truncated diamond-shaped airfoil sections has been studied at supersonic Mach numbers. Use is made of linearized theory to evaluate the surface pressures. Comparison is made between the drag of these wings, and similar wings with sharp trailing edges, for various aspect ratios and thickness ratios over a range of stream Mach number. The calculations of the drag characteristics for these wings show that significant drag reductions are possible at high supersonic speeds by the use of blunt trailing edges. These drag reductions are relatively independent of aspect ratio for the rectangular wings but depend considerably on aspect ratio for the delta wings; the smaller aspect ratios show the larger drag reductions. Calculations of the spanwise distribution of drag are included, to compare further the effect of a blunt trailing edge on the drag for different aspect ratios. The results of this study are presented in Technical Note 2828.

In the study of unsteady flows, two methods of using the concept of linearized characteristics have been derived for the one-dimensional unsteady flow in a tube that is rotated about an axis perpendicular to the axis of the tube. One of the methods corresponds to that used by Ferri in his basic work on the subject. Solutions have been obtained by both methods for boundary conditions that allow analytic solutions. Comparison shows that both methods give the same results, but there are significant differences in their application. This work is presented in Technical Note 2794.

Steady, shock-free, transonic diffuser flow as affected by a small, short-time lowering of back pressure has been investigated analytically. A previous exploratory study by Kantrowitz (Technical Note 1225) indicated that a short-time lowering of the back pressure in this type of diffuser results in a stationary or trapped shock near the critical sonic channel throat. The new study (Technical Note 2797) considers the contribution of a higher-order term neglected in the earlier study. This more accurate approximation shows that the shock is not stationary or trapped in the diffuser unless it is supported by a negative steady-flow back pressure; thus, the result is no longer in disagreement with steady-flow solutions for stationary shocks.

A theoretical investigation to develop a procedure for calculating three-dimensional supersonic flows by the method of characteristics has been completed and is reported in Technical Note 2811. The flow was assumed to be adiabatic and inviscid, but may be rotational, and the gas may exhibit both thermal and caloric imperfections. For flows where the Mach number is very large compared to 1, an approximate method was deduced which considerably reduces the complexity of the calculations.

In view of the low temperatures and the consequent condensation processes encountered in wind-tunnel research at high supersonic speed, a program was initiated at the National Bureau of Standards, under NACA sponsorship, to determine the basic properties of liquid air and its components, to aid in the development of the theory of condensation in wind tunnels. In this study the condensation pressure of air was determined over a range of temperatures from 6° to 85° K. The experimental results reported in Technical Note 2869 are slightly higher than calculated values based on the ideal solution law. Heat of vaporization of oxygen and nitrogen was determined at four temperatures ranging from about 68° to 91° K. and 62° to 78° K., respectively.

The results of an investigation to obtain the effect of variable viscosity and thermal conductivity on high-speed slip flow between concentric cylinders are presented in Technical Note 2895. The differential equations of slip flow were first solved by Schamberg assuming that the coefficients of viscosity and heat conduction of the gas were constant. The problem is solved for variable coefficients of viscosity and thermal conductivity. The method, starting with the solution for constant coefficients, enables one to approximate the solution for variable coefficients after one or two steps. This work was conducted at the University of Washington under contract with the NACA.

Boundary Layers and Stream Mixing

Determination of the position at which the laminar boundary layer separates from a surface has been the subject of much theoretical investigation. Recently, a simplified method for estimating the separation point of a compressible boundary layer has been developed in Technical Note 2892. This method is based on Von Doenhoff's simplified solution for the incompressible case together with Stewartson's transforms which express the compressible laminar boundary layer in terms of an equivalent incompressible laminar boundary layer. Application of the method indicates that an upstream movement of the laminar separation point accompanies an increase in Mach number.

The flow over infinite wedges has been investigated theoretically to test a conclusion previously reached by the use of Schlichting's approximate method for the calculation of the laminar boundary layer. By the use of the velocity profiles determined by Hartree from a numerical solution of the boundary-layer equations for wedge flows, and by the use of Lin's rapid method for the calculation of the critical Reynolds number of a velocity profile, the result is obtained that a thick velocity profile on one wedge can be more stable than a thinner profile on a wedge of different angle although the velocity outside the boundary layer and the pressure gradient are the same for both profiles. This result confirms the conclusion reached by the use of Schlichting's approximate method. This investigation, which is reported in Technical Note 2976, also leads to the inference that the calculated effects of a change in boundary-layer thickness on the stability and on the local roughness Reynolds number should be essentially unchanged by replacing the Schlichting single-parameter family of velocity profiles by the Hartree single-parameter family of velocity profiles.

Extensive regions of laminar flow with resultant large reductions in drag may be attained at large values of Reynolds number by means of continuous suction of the boundary layer (Report 1025) provided that the airfoil surfaces are maintained sufficiently smooth and fair. To provide quantitative information on the stabilizing effect of continuous suction in the presence of finite disturbances, an extension of the previous investigation, Technical Note 2796, was made in the Langley low-turbulence pressure tunnel on an NACA 64A010 airfoil having deliberately added two- and three-dimensional surface disturbances. Continuous suction allowed only a slight increase in the size of a small, finite surface disturbance required to cause premature boundary-layer transition as compared with that for the airfoil without suction. With or without continuous suction, the maximum size of a protuberance that will not cause premature transition is small with respect to the boundary-layer thickness.

Most available experimental values of average drag coefficient for laminar flat-plate flow have been obtained by total-pressure surveys of the boundary layer. At supersonic speeds most of these data have shown discrepancies in the range of 10 to 100 percent between theoretical and apparent experimental average flat-plate friction drag coefficients. An investigation of the causes of these discrepancies is treated in Technical Note 2891. Of the many factors investigated, only the effect of total-pressure probe size was found to be significant. A correlation describing the relation between friction-drag discrepancy and probe-tip height is presented.

For high-speed flight at very high altitudes, a knowledge of the behavior of air flow in rarefied gases is of importance. The first-order solution for the laminar compressible boundary-layer flow over a flat plate at constant wall temperature is given in Technical Note 2818. The effect of slip at the wall as well as the interaction between the boundary-layer flow and the outer stream flow are taken into consideration. The solution indicates a decrease in heat transfer and, for supersonic flow, an increase in skin friction relative to the standard continuum solution.

An investigation has been conducted to determine the average skin-friction drag coefficients of a parabolic body of revolution having a fineness ratio of 15. Average skin-friction drag coefficients were obtained from boundary-layer total-pressure measurements on the body in water at Reynolds numbers from 4.4×10^6 to 70×10^6. The body was sting-mounted at a depth of two maximum diameters. The average skin-friction drag coefficient for the forward 69 percent of the basic body in incompressible flow is very nearly the same as that for flat plates. The distribution of boundary layer around the body is not uniform over part of the Reynolds number range, apparently being affected by a very small cross-flow component. The results of this investigation are presented in Technical Note 2854.

Systematic experiments have been conducted over the past few years to measure the magnitude of turbulent skin friction at high flight velocities. Such experiments are required in order to determine the amount of aerodynamic heating, as well as the drag of supersonic missles and aircraft. One such investigation covered a range of Mach numbers from 0.5 to 3.6, and a range of Reynolds numbers from 4 to 32 million. A summary of the more significant results of the study has been published by the Institute of Aeronautical Sciences in the July 1953 issue of the Journal of Aeronautical Sciences.

The experiments showed no appreciable effect of moderate changes in pressure distribution on average skin friction. At both subsonic and supersonic velocities, the skin-friction coefficient was observed to depend only to a small extent on body fineness ratio. For each body tested, however, the effect of Mach number was found to be large, amounting to approximately a 50-percent reduction in skin-friction coefficient as the Mach number was increased. This effect of Mach number was found to be the same for all Reynolds numbers investigated.

At high subsonic speeds, the boundary layer at a given Reynolds number is thicker than that at lower speeds because of the large temperature gradient across the boundary layer. This thick boundary layer effectively distorts the body contours and thereby causes deviations from the pressure distributions predicted by theories which take no account of viscous effects. A simplified analysis has been made, based on results obtained by Busemann in 1935. Busemann indicated that the velocity profile across the boundary layer formed on an insulated flat plate is approximately linear at high Mach numbers. A comparison of results from the theoretical analysis with experimental pressures from a flat plate at a Mach number of 6.86 (presented in Technical Note 2773) shows good agreement at the low angles of attack except for the low-pressure surface, where the agreement is poor. It was found that at a Mach number of 6.86, pressures over an airfoil with a circular-arc profile can be predicted with fair accuracy over a wider range of angle of attack than is possible for the flat plate.

The behavior of the boundary layer about a cone at angles of attack is of particular interest in connection with the design of inlets and missile fuselages. In Technical Note 2844, the laminar boundary-layer flow in the plane of symmetry of a circular cone at large angles of attack in a supersonic stream has been analyzed. Beyond a certain critical angle of attack, it is found that boundary-layer flow does not exist in the plane of symmetry, thus indicating separation. This critical angle is presented as a function of Mach number and cone vertex angle.

The reflection of a weak shock wave from a boundary layer along a flat plate has been investigated by Cornell University. The problem has been simplified by dividing the flow field into a viscous layer near the wall and a supersonic potential outer flow. Ordinary linearized theory has been applied to the outer flow inasmuch as the study, presented in Technical Note 2868, has been restricted to infinitesimal compression waves and only small perturbations are encountered. The paper deals primarily with the case of laminar flow, and the boundary-layer treatment is based upon the momentum-integral equation previously derived by Howarth. A second report on the subject, Technical Note 2869, gives the rate of decay of the disturbances and the character of the disturbances upstream and downstream from the point of incidence.

In a simplified inviscid model of shock-wave boundary-layer interaction, Tsien and Finston replaced the boundary layer by a uniform subsonic stream bounded on one side by a solid wall. This model fails to simulate the separated region that generally appears in a laminar boundary layer subjected to an oblique shock-wave of moderate strength. In order to introduce a main feature of such a dead-air region, the model has been modified by replacing the solid wall by an interface with fluid at rest along which the boundary condition of constant pressure must be satisfied. The distortions of the upper and lower surfaces of the simulated boundary layer are found to be similar, except in the immediate vicinity of the incident shock, to the contour computed for the interface between supersonic flow at the same Mach number and a dead-air region. These results, reported in Technical Note 2860, support the inference that the separated region dominates the behavior in the immediate vicinity of the shock and that the upper surface of the boundary layer behaves, in that vicinity, substantially as if the entire boundary layer were replaced by a dead-air region.

Results of a flight investigation made at free-stream Mach numbers up to about 0.77, to determine the effect of laminar and turbulent boundary layers on the chordwise pressure distribution over an airfoil in the presence of shock at full-scale Reynolds numbers (up to 21×10^6), are reported in Technical Note 2765. In this study, boundary-layer and pressure-distribution measurements were made on a short-span airfoil built around the wing of a fighter airplane. The results indicate very little difference in pressure distribution, and hence in the forces and moments acting on the airfoil, with laminar and turbulent boundary layers extending up to the position of shock. These results are in contrast to those of other investigations made at low Reynolds numbers (up to 3×10^6) which indicated large pressure differences extending over an appreciable extent in the chordwise direction.

An experimental investigation has been made to study the airflow characteristics in the vicinity of a rectangular wing of low aspect ratio by means of photographs of a tuft grid located at various chordwise positions along and behind the airfoil. The results, reported in Technical Note 2790, showed that, at the foremost chordwise station considered (0.125c), the trailing vortices were distinctly visible and indicated a rapid rolling up of the trailing vortex sheet into the vortex cores. The cores appeared to leave the wing at approximately 0.125c with an initial slope somewhat less than the wing angle of attack. The slope decreased with increase in distance behind the wing. The slopes of the vortices are predicted very well by the theory of Bollay for low-aspect-ratio wings. The photographs showed no lateral displacement of the vortices with change in angle of attack. The chordwise growth of lift, and the net lift on the model, could be calculated with good accuracy from information obtained by the tuft-grid photographs.

The mean-camber surfaces for wings having uniform chordwise loading and arbitrary spanwise loading in subsonic flow have been determined and recorded in Technical Note 2908. It is shown that, for the design of such wings, the slope of the mean-camber surface at any point can be determined by a line integration around the wing boundary. By an additional line integration around the wing boundary, this method is extended to include the case where the local section lift varies with spanwise location (the chordwise loading at every section still remaining uniform).

The high landing speeds of modern aircraft have dictated a need for studies of the effects of high speeds (Mach numbers between 0.1 and 0.4) on the maximum lift. An investigation has accordingly been made to determine the effect of such Mach number variations on the maximum lift of four NACA 6-series airfoil sections. The study, reported in Technical Note 2824, was made for several values of Reynolds number and indicates that marked reductions in maximum lift may, in some cases, accompany increases in Mach number from 0.1 to 0.4.

Results of work, presented in a previous annual report, to improve the characteristics of airfoils of large thickness ratios emphasized the potential gains to be realized, for both range and maximum lift considerations, from the application of boundary-layer control as a means of eliminating wing-flow separation.

In order to evaluate the system more completely, a high-aspect-ratio wing (aspect ratio 20) having very thick root sections and equipped with a single suction slot at the 60-percent-chord station on the upper surface was investigated. The results of this study, reported in Technical Note 2980, show that discrete design of the suction slot to insure optimum spanwise suction control, resulted in lift-drag ratios as high as 30.8 at a lift coefficient of 0.9 and a maximum lift coefficient of 4.2 could be realized with flaps deflected and full-span boundary-layer control applied. The drag equivalent of the power expended for the boundary-layer control and the effects of wing leading-edge roughness are also noted in the report.

An investigation of the low-speed aerodynamic characteristics of a two-dimensional, 10.5-percent-thick, symmetrical airfoil with area suction near the leading edge has been completed. The results of the investigation have been presented in Technical Note 2847. The maximum lift of the basic airfoil without suction was 1.3. With a suction flow coefficient of 0.0014, a maximum lift coefficient of 1.78 was obtained.

Technical Note 2887 presents the results of a study of the stability of the mixing of two parallel streams in a gas. It is shown that, when the relative speed of the two parallel streams exceeds the sum of their respective velocities of sound, subsonic oscillations cannot occur and the mixing region may be expected to be stable with respect to small disturbances. It is further shown that, when viscosity and heat conductivity are neglected, if the flow can execute a small, neutral, subsonic disturbance, it can also execute self-excited oscillations of longer wave lengths, and damped oscillations of shorter wave lengths. Additional developments of the mathematical theory of asymptotic solutions show that, at high Reynolds numbers, the damped oscillations in a strictly parallel main flow have a structure similar to that of the vorticity field in fully developed flow. This work was conducted at the Massachusetts Institute of Technology.

Turbulence

Measurements, principally with a hot-wire anemometer, were made at the National Bureau of Standards, under NACA sponsorship, in fully developed turbulent flow in a 10-inch pipe at speeds of 10 and 100 feet per second. This work, conducted under sponsorship of the NACA, is reported in Technical Note 2954. It is shown that rates of turbulent-energy production, dissipation, and diffusion have sharp maximums near the edge of the laminar sublayer and that there exists a strong movement of kinetic energy away from this point and an equally strong movement of pressure energy toward it. It is suggested that the flow field may be divided into three regions: wall proximity where turbulence, production, transfer, and viscous action are of about equal importance; the central region of the pipe where energy diffusion predominates; and the intermediate region where the local rate of change of turbulent-energy production dominates the energy received by diffusive action.

Wake development behind circular cylinders at Reynolds numbers from 40 to 10,000 was investigated by hot-wire techniques in a low-speed wind tunnel of the California Institute of Technology, under contract with the NACA. As reported in Technical Note 2913, the Reynolds number range of periodic vortex shedding is divided into two distinct subranges. In the stable range, Reynolds numbers from 40 to 150, regular vortex streets are formed and no turbulent motion develops, the vortices decaying by viscous diffusion. The range of Reynolds numbers from 150 to 300 is a transition region to the irregular range in which turbulent velocity fluctuations accompany the periodic formation of vortices. The diffusion is turbulent and the wake becomes fully turbulent in 40 to 50 diameters. The turbulence is initiated by laminar-turbulent transition in the free layers which spring from the separation points on the cylinder. An annular vortex street was observed in the wake of a ring.

In Technical Note 2878, a linearized analysis is presented on the combined effect of a series of damping screens followed by an axisymmetric-stream convergence, or divergence, upon the longitudinal and lateral turbulence velocity fluctuations, scales, correlations, and spectra of a turbulence field described by a triple Fourier integral in the absence of viscosity. An approximate method of taking into account the effects of turbulence decay upon the mean-square fluctuations velocities thus obtained is also presented.

In measurements made with a hot-wire anemometer in a supersonic stream, where a detached bow wave stands ahead of the wire, proper interpretation requires a knowledge of the effects of convection of turbulence through the shock wave. The passage of a single representative shear wave through a plane shock is treated in Technical Note 2864. The analysis indicates the refraction and modification of the shear wave with simultaneous generation of an acoustically intense sound wave.

Aerodynamic Heating and Heat Transfer

An iteration method is presented in Technical Note 2916 for solving the laminar-boundary-layer equations for compressible flow in the absence of a pressure gradient wherein the temperature variation of all the fluid thermal properties is considered. Friction and heat-transfer characteristics have been calculated for a stream temperature of $-67°$ F., for Mach numbers from 1 to 10, with values of heat capacity, conductivity, and viscosity determined from experiment. Consideration of the temperature variation of all the fluid thermal properties causes the recovery factor to decrease substantially with increasing Mach number. Moreover, the heat-transfer rate is found to be proportional to the difference between an effective enthalpy, which is a function of both the surface temperature and stream Mach number, and the surface enthalpy. In contrast, the heat-transfer rate is approximately proportional to the difference between the recovery enthalpy and the surface enthalpy for solutions which employ a constant Prandtl number. The calculated skin friction and heat-transfer rates, based upon the use of the Sutherland equation for viscosity and a Prandtl number of 0.75, however, are in excellent agreement with the results of the present analysis.

HIGH-SPEED AERODYNAMICS

Airfoils

A general theoretical method has been developed for determining the airfoil shape having the least possible drag for a variety of structural criteria. This method, described in Technical Note 2787, is based on shock-expansion theory and is, therefore, applicable at hypersonic velocities as well as supersonic velocities. It is found, in all cases, that the simpler linearized theory is adequate for determining the shape of the optimum profile, even at Mach numbers approaching infinity. However, shock-expansion theory must be used to calculate the drag.

A theoretical study has been made of the aerodynamic characteristics at small angles of attack of a thin, double-wedge profile in the range of supersonic flight speed in which the bow wave is detached. The aerodynamic characteristics of a profile of given thickness ratio are found to have little variation with free-stream Mach number as the Mach number passes through 1. As the Mach number is increased to higher values, however, the lift-curve slope rises to a pronounced maximum in the vicinity of shock attachment and then declines. These findings, reported in Technical Note 2832, are in contrast to previous results for the drag coefficient at zero angle of attack, which was found to decrease progressively as the Mach number increased above 1.

An investigation of the flow past a 12-percent-thick biconvex circular-arc profile at zero angle of attack has been conducted utilizing the interferometer technique. The purpose of the investigation was to obtain pressure distributions on the model and Mach number distributions in the field around the model with laminar and turbulent boundary layers and to study the flow conditions along and at the bases of the shock waves that occurred at the higher Mach numbers and that interacted with turbulent boundary layers. The range of Mach numbers was 0.61 to 0.89. The results presented in Technical Note 2801 show that sonic speed is first reached at an indicated Mach number of about 0.74 and the contours of constant Mach number in the supersonic region change from the symmetrical to the asymmetrical type at an indicated Mach number of about 0.78.

Wings and Bodies

Calculations have been made by means of linear theory to determine the supersonic wave drag of a nonlifting, symmetrical, double-wedge-profile, delta wing, the thickness ratio of which varies linearly in the spanwise direction. In general, it was found, from the results presented in Technical Note 2858, that a delta wing with linearly varying thickness ratio can have less wave drag than a constant thickness ratio delta wing of the same plan form, when both wings have either the same projected frontal area or the same internal volume. The thickness distributions for minimum drag and the corresponding values of the ratio of the drag of a wing with linearly varying thickness ratio to a wing with constant thickness ratio were found.

On the basis of linearized supersonic-flow theory, equations for the span load distributions resulting from constant angle of attack, steady rolling velocity, steady pitching velocity, and from constant vertical acceleration have been derived for a series of thin, sweptback, tapered wings. The results, which are valid at those supersonic speeds for which the wing leading edge is subsonic and the wing trailing edge is supersonic, are published in Technical Note 2831. Charts are presented which permit rapid estimation of the load distribution for given values of aspect ratio, taper ratio, Mach number, and leading-edge sweepback.

Few data are available to serve as a guide in the design of the aft sections of supersonic bodies or as a basis for estimating the wave drag and the associated aerodynamic loads. Available data indicate that potential theory can be used to predict these characteristics adequately for most design purposes. In Technical Note 2972 are presented the afterbody pressure distributions and wave drags calculated on the basis of a second-order theory for conical, tangent-parabolic, and secant-parabolic boattails for Mach numbers from 1.5 to 4.5, area ratios from 0.20 to 0.80, and boattail angles from 3° to 11°. For a specific Mach number, area ratio, and fineness ratio, the conical boattail has the smallest wave drag of the three types considered.

Technical Note 2944 presents zero-lift drag data of a slender body of revolution with and without stabilizing fins attached. Results from several wind tunnel studies and from free-air-flight tests are compared. These data cover a Reynolds number range from about 1×10^6 to 40×10^6 for the wind-tunnel models and 12×10^6 to 140×10^6 for the free-flight models. The Mach numbers covered include 1.5 to 2.4 in the wind tunnels and 0.85 to 2.5 in flight.

Research Equipment and Techniques

Precise measurement of low absolute pressures in supersonic wind tunnels has been a problem requiring solution for some time. A precise, stable, rapid-response Pirani gage, described in Technical Note 2946, has been developed at Langley as one possible soultion to this problem. Because of the small size of the gage it has low lag characteristics, and can be mounted close to the pressure orifices, which is an advantage for many installations. The paper describes techniques of calibration, and use of this gage. Measurements of reading errors not exceeding ±2 percent, errors in lag not exceeding 1 second, and errors in calibration shift of 2 percent per year are shown. A description is also given of operating equipment for recording the pressures.

As the result of the need for a convenient and systematic means of selecting, designing, or redesigning a pressure-measuring system to meet the time requirements of a particular installation, a method has been obtained at Langley for the determination of time lag in pressure-measuring systems incorporating capillaries. Calculated and experimental data, presented in Technical Note 2793, show that response time in a pressure-measuring system incorporating capillaries is a function of the orifice pressure, initial pressure differential, and system volume. The study also shows that the response time is directly proportional to capillary length and to the viscosity of the gas in the capillary, and inversely proportional to the fourth power of the capillary diameter.

Hot-wire turbulence-measuring equipment has been developed to meet the stringent requirements involved in the measurement of fluctuations in flow parameters at supersonic velocities. The higher mean speed necessitates the resolution of higher frequency components than at low speed, and the relatively low turbulence level present at supersonic speed makes necessary an improved noise level for the equipment. The equipment is adaptable to all-purpose turbulence work with improved utility and accuracy over that of older types of equipment. This research was carried out by the National Bureau of Standards under the sponsorship of the NACA and is reported in Technical Note 2839. Sample measurements are given to demonstrate the performance of the equipment.

An experimental investigation has been conducted to determine feasibility of using an X-ray densitometer to measure air densities in disturbed flow fields at high supersonic speeds. It has been concluded from measurements in conical flow fields that density can be determined with sufficient accuracy at the low densities encountered to establish the instrument as a useful research tool. This work is reported in Technical Note 2845.

A low-cost interferometer that is easy to adjust and has a large field of view has been investigated. This instrument, which is based on a principle discovered by Kraushaar, uses small diffraction gratings to produce and recombine separate beams of light. The usual two-parabolic-mirror schlieren system can be converted inexpensively to a diffraction-grating interferometer. Experimental data, presented in Technical Note 2827, have been obtained which verify the ability of the instrument to provide valid and reliable measurements of air density.

A new shadowgraph technique for the observation of conical-flow phenomena in supersonic flow has been investigated. The particular advantage of this technique over conventional types of shadowgraph or schlieren systems is that it permits observation of the conical-flow phenomena in a plane normal, or nearly normal, to the axis of propagation. As presented in Technical Note 2950, the principle of the shadowgraph is utilized by superimposing a conical light field upon a conical flow field in such a way as to project the shadowgraph on a propeller screen within the test section of the tunnel. Preliminary tests with a triangular wing gave satisfactory results.

A new high-speed photographic technique has been developed which employs a variable-frequency light synchronized with a commercially available 16-millimeter high-speed motion-picture camera without appreciable alterations to the camera. The technique is described and results obtained by this technique of photographing the flow past models in a wind tunnel employing the schlieren method of flow visualization are presented in Technical Note 2949. The photographs show that the new technique, through the use of extremely short exposure times (about 4 microseconds), provides more sharply defined pictures throughout the flow field than were obtained by conventional techniques.

STABILITY AND CONTROL

Static Stability

Requirements for satisfactory high-speed performance have resulted in aircraft configurations that differ in many respects from previous designs. The low-speed longitudinal stability characteristics of wing configurations suitable for high-speed flight, including the effect of high-lift devices, have been the subject of extensive studies. The static lateral stability characteristics of wing configurations suitable for high-speed flight, including high-lift devices, have been the subject of study in the Langley stability tunnel. Recently reported were the results of a study utilizing a 45° sweptback wing in combination with a fuselage. These data, presented in Technical Note 2819, show that for moderate and high values of lift an increase in the span of a trailing-edge flap with or without a leading-edge slat generally caused an increase in the effective dihedral and directional stability. The increments in the static-lateral-stability parameters caused by the high-lift devices could be calculated with fair accuracy by using the measured lift and drag and a simple correction for the degree of sweep.

One problem associated with the use of wing sweepback is the premature stall of the tip region. This stalling causes the aerodynamic characteristics to depart from their usual linear trends at low angles of attack. Wing twist, wing-section camber, or combinations of the two can provide a more acceptable stall pattern. Technical Note 2775 presents the results of an experimental investigation in the Langley stability tunnel to determine the effects of linear spanwise twist and a combination of camber and twist on the low-speed static and rotary characteristics of a 45° sweptback wing. It was found that a combination of twist and camber was more effective than twist alone in extending the linear range of several of the stability terms to higher values of lift and in improving the efficiency of the wing at moderate angles of attack. Twist or combined twist and camber produced only small changes in the maximum lift coefficient.

To provide additional information on the forces and rolling moment due to sideslipping at supersonic speeds, a generalized family of sweptback, tapered wings has been studied through the use of linearized theory. This analysis, reported in Technical Note 2898, is generally applicable to those supersonic speeds for which the wing trailing edge is in a supersonic flow field.

Available theories for calculating the stability characteristics for horizontal-vertical tail combinations in sideslip are rather limited. In order to check the accuracy of one such theory which utilizes a method found to be effective in predicting wing span loadings, an experimental investigation was conducted in the Langley stability tunnel. The effect of vertical location of the horizontal tail and of horizontal tail span on the aerodynamic characteristics of an unswept tail assembly were determined as a function of sideslip. The results, reported in Technical Note 2907, show that the method used does provide a simple, effective means of determining the aerodynamic characteristics of intersecting surfaces at subsonic speeds. It was found that the induced loading carried by the horizontal tail produced a rolling moment about the point of attachment to the vertical tail which was strongly influenced by horizontal-tail span and vertical location. The greatest effects of horizontal-tail span on the rolling-moment derivative of the complete tail assembly were obtained for horizontal-tail locations near the top of the vertical tail.

An experimental investigation was made at low speed in the Langley stability tunnel to determine the origin of large yawing moments which have been found to occur for some fuselages inclined at large angles of attack. The results (Technical Note 2911) show that increases in yawing moment are caused by asymmetrical disposition of a pair of trailing vortices emanating from the nose of the fuselage. It was found that a ring or surface roughness near the fuselage nose causes a large decrease in magnitude of the yawing moments in the critical angle-of-attack range.

The magnitude of the changes in aerodynamic forces and moments resulting from propeller pitch reversal has been studied utilizing a twin-engine airplane model in the Langley 300 mph 7- by 10-foot tunnel. The results of the investigation, reported in Technical Note 2979, indicate that the lift, longitudinal-force, and pitching-moment coefficients varied almost linearly with total thurst coefficient through the negative and positive thrust ranges. The lateral-force, yawing-moment, and rolling-moment coefficients were found to vary as approximately linear functions of asymmetric-thrust coefficient. Based on an analysis of the data, a method is suggested which will give a reasonable estimate of the effects of thrust reversal on the aerodynamic characteristics of an airplane through the use of existing wind-tunnel data. For extreme asymmetric thrust conditions, the rudder and aileron control power can be marginal or inadequate.

The effects of a propeller slipstream on the aerodynamic characteristics of wing and wing-nacelle configurations at high subsonic Mach numbers have been a recurring question to aircraft designers. Tests have recently been conducted in the Langley 24-inch high-speed tunnel to determine characteristic effects of a simulated propeller slipstream on the aerodynamic characteristics of an unswept wing panel with and without nacelles. The propeller slipstream was simulated by a calibrated jet of air. Lift, drag, and pitching moment were measured at angles of attack or 0° and 3° through a range of Mach numbers from 0.30 to 0.86. The test results, reported in Technical Note 2776, show that, for Mach numbers of the propeller slipstream equal to and 10 percent greater than those of the free stream, there were no significant changes in lift and pitching-moment coefficients for the configurations investigated. However, the Mach number for drag rise near zero lift was deceased because of the propeller slipstream.

Dynamic Stability

Some present-day high-speed airplanes exhibit an undamped, low-amplitude, lateral oscillation in flight. This instability may be the result of changes in the damping of the lateral motion associated with changes in amplitude of the oscillation. The damping in yaw of a fuselage-vertical-tail combination has previously been determined by the free-oscillation technique in which the amplitude of the motion decreased logarithmically after initial displacement. As an extension to that investigation, a similar model oscillating continuously in yaw has been studied in the Langley Stability Tunnel to determine the influence of amplitude and frequency on aerodynamic damping. A report on the results, Technical Note 2766, indicates that a reduction in damping in yaw appeared for the smallest amplitudes of oscillation. The decrease in lateral damping with reduction in frequency was slightly greater than the small variation predicted by finite-span unsteady-lift theory but not so large as the variation indicated by two-dimensional theory.

Previous analytical studies indicate that the natural frequencies of a body-tail combination in pitch and yaw will be affected by steady rolling. One of the frequencies will increase and the other decrease to a point where instability is encountered. To obtain experimental results with which to evaluate the adequacy of such analyses, tests were made with a free-flight, body-tail combination in steady roll. Results of this study, reported in Technical Note 2985, indicate that good agreement was obtained between experiment and theory for the deterioration of stability with increasing roll rate and the prediction of the roll rate at which instability would occur.

The determination of the longitudinal stability derivatives from flight data has been a relatively difficult task because the wind-tunnel technique of permitting only one variable to change at a time, while constraining the rest of the variables, cannot always be used. However, matrix methods employing the equations of motion have been found to be particularly useful in determining stability derivatives from complex flight data. In Technical Note 2902, three matrix methods involving various degrees of refinement are presented for determining the longitudinal-stability derivatives from transient flight data. The choice of methods depends on the measurements available and all indicate that good accuracy can be obtained.

Curve-fitting procedures have also been found to be applicable to the calculation of the stability parameters of an airplane from flight data. Because of the importance of knowing the errors in such methods, an analysis has been made of the errors in the parameters obtained from a curve-fitting process. Technical Note 2820 reports this study and gives an example of the process of finding the errors in the calculated stability parameters of an airplane.

Damping Derivatives

To provide additional information on the contribution of various tail configurations to the damping of the lateral oscillations of airplanes and missiles at supersonic speeds, expressions for the velocity potentials, span loadings, and corresponding force and moment derivatives for a number of tail arrangements performing a steady rolling motion have been derived and are presented in Technical Note 2955. Illustrative variations of the rolling stability derivatives for several series of tail shapes, as well as pressure distributions and sample span loadings, are included. Some consideration is also given to the problem of wing-tail interference.

The calculation of the rolling and yawing moments due to rolling has received extensive treatment at low angles of attack where the variation of lift with angle of attack is linear. At high angles of attack where lift varies in a nonlinear manner, little attention has been given to the problem of calculating these important stability factors. The techniques for a method of calculating wing lift characteristics in the nonlinear range was applied to the calculation of the rolling-and yawing-moment coefficients due to rolling for unswept wings with or without flaps or ailerons. This method, presented in Technical Note 2937, permits calculations to be made somewhat beyond maximum lift for wings employing airfoil sections which do not display large discontinuities in the lift curves. Calculations can be made up to maximum lift or wings with discontinuous twist such as that produced by partial-span flaps and/or ailerons.

In many cases, satisfactory lateral oscillatory stability cannot be obtained through reasonable geometric changes to present-day high-speed airplanes. Thus, artificial stabilization devices as means of providing satisfactory damping of the lateral oscillation are of considerable interest. An investigation has been carried out in the Langley free-flight tunnel on a free-flying dynamic airplane model equipped with an artificial stabilization device as a means of changing the model's important dynamic lateral stability terms to evaluate the effect of these artificial terms on the dynamic lateral stability and control characteristics of the airplane model. The results of this investigation, reported in Technical Note 2781, show that the only stability derivative that provided a large increase in damping of the lateral oscillation without adversely affecting other flight characteristics was the yawing moment due to yawing. Increasing the rolling moment due to rolling to moderately large negative values produced substantial increases in the damping of the lateral oscillation, but resulted in objectionable roll control. Increases in the rolling moment due to yawing and the yawing moment due to rolling in the positive direction produced an increase in damping, but caused an undesirable spiral tendency.

Stalling

Statistics indicate that a large percentage of all fatal private flying accidents in the past have occurred because of pilot error; in more than half of these accidents the airplane stall has been involved. Accidents of this nature are referred to as "stall-spin" accidents and occur primarily in the incipient phase of a spin, that portion of the motion immediately following the stall and before a spin fully develops. A technique has been developed in the Langley spin tunnel which utilizes free dynamic models to study incipient spinning. The model is catapulted into still air in such a manner that stalled flight occurs. The ensuing motion at and beyond the stall is studied. The results of an investigation utilizing this technique on a model, typical of a present day four-place, personal-owner airplane, are presented in Technical Note 2923. These results show that soon after the model stalled, it unstalled, became inverted for a part of its motion, before again stalling and continuing toward a developed spin. The initial rates of rotation were such that, by inference, proper control movements soon after the roll-off could terminate the motion.

Flight tests have shown that when an airplane is in stalled flight and autorotative moments are present, together with violently changing burbled flow, a pilot cannot maintain satisfactory lateral control, even with special devices, such as spoilers, which give ample rolling moments. The difficulty is that the autorotative moments build up so rapidly that the pilot cannot react quickly enough to maintain the airplane at the desired lateral attitude. A flight study utilizing a typical light high-wing monoplane has been made by the Texas A and M Research Foundation, under NACA sponsorship, to furnish the designer with quantitative design information from which the proper combination of variables may be selected to insure satisfactory control near the stall. The results of the study are presented in Technical Note 2948. In the study, satisfactory lateral control was obtained even under conditions simulating extremely gusty air at angles of attack up to approximately 2° below that for maximum lift. This 2° margin was substantially the same, both with full power and with the engine throttled, throughout the range of center-of-gravity locations investigated. For a plain untwisted wing, this stall margin was obtained with widely different elevator deflections for the range of power and center-of-gravity locations considered. With the wing twisted (8° of washout), satisfactory lateral control was obtained under all conditions tested, even at angles of attack beyond that for maximum lift. The desired condition, that is, having sufficient up elevator control to accomplish three-point landings, but insufficient to exceed the angle of attack for satisfactory lateral control, was attained under limited conditions when 8° of washout or a full-span slot was utilized.

Automatic Control and Stabilization

Considerable interest is being shown in the use of automatic stabilization devices for improving the damping of the lateral oscillation of aircraft designed for flight at transonic and supersonic speeds. A method for determining the effects of the dynamic response of an autopilot on the lateral stability of an aircraft-autopilot combination is described in Technical Note 2857. The method is applied to the analysis of the lateral motion of an airplane equipped with a second-order automatic, yaw-rate damper. For any flight condition of the airplane, an optimum combination of values of autopilot natural frequency and damping ratio are shown to exist for any given value of gain or damping. A simple analytical expression is derived for obtaining a close approximation to these optimum points and is used to determine the maximum amount of damping obtainable under various flight conditions. The report illustrates a simple method of designing yaw dampers.

The addition of an autopilot to an airplane introduces many variations in the manner in which airplane motions can be controlled. As part of a general theoretical investigation of airplane automatic control systems, an analysis of a pitch-attitude control system has been made and reported in Technical Note 2882. This study shows the effects of Mach number and altitude on the transient response of a swept-wing fighter airplane equipped with an attitude control system with and without rate feedback. In this study, the dynamic characteristics of the airplane were estimated from theory and available experimental data. The frequency-response characteristics of the autopilot considered were obtained from actual tests of an autopilot. In addition to the study of autopilot characteristics which will give optimum response for each altitude and Mach number condition, the effects on airplane response of holding the autopilot characteristics constant while varying flight conditions were also determined. The results indicate satisfactory control of aircraft attitude can be obtained with this system, although the system will not provide precise control of airplane flight path.

INTERNAL FLOW

Studies of the performance characteristics of two-dimensional diffusers, proportioned to insure reasonable approximation of two-dimensional flow, have been completed at Stanford University. The diffusers had identical entrance cross sections and discharged directly into a large plenum chamber. The test program included wide variations of diffuser divergence angle and length. A few tests were made with asymmetric diffusers. Some tests were also made to determine the effects of addition of a short exit duct of uniform section and of installation of a thin, central, longitudinal partition. This work is reported in Technical Note 2888.

PROPELLERS FOR AIRCRAFT

The aerodynamic design of a propeller is influenced considerably by structural design considerations. This matter, insofar as blade centrifugal stress is concerned, has received attention. In Technical Note 2851, a solution is reported for the distribution of cross-sectional area along the propeller blade required for constant centrifugal stress over most of the blade. The study shows that by applying a constant minimum value of thickness-chord ratio to the required radial distribution of cross-sectional area, propellers with good efficiency at high Mach numbers are realized. In a comparison of two propellers designed for a Mach number of 0.9 and an advance ratio of 2 (forward velocity divided by propeller diameter and rotational speed), with the same allowable design stress and differing only in the manner in which the area variation was applied, a blade having a constant minimum thickness-chord ratio of 2 percent was 7 percent more efficient than a rectangular-plan-form propeller with a 2-percent-thick tip.

The analytical work reported last year on the effects of wing and nacelle interference on the first-order vibratory stresses on propellers has been extended to provide a method of predicting the upwash characteristics for a wide range of propeller locations for tractor-type installations on airplanes with wings of arbitrary plan form. This information is presented in Technical Notes 2795 and 2894. In addition to these data, experimental data were obtained to verify the method of upwash prediction and to provide more detailed information on other characteristics of flow fields at the propeller plane. This latter data is reported in Technical Note 2957.

In the interests of propeller-noise abatement, charts have been prepared to permit the preliminary selection of a propeller for near-optimum cruising and take-off performance coupled with minimized propeller noise. These charts, presented in Technical Notes 2966 and 2968, apply to transport airplanes at flight Mach numbers up to 0.8 and are of sufficient scope to permit fairly rapid evaluation of the propeller performance for engine power ratings of 1,000 to 10,000 horsepower.

SEAPLANES

The increased takeoff and landing speeds of water-based aircraft and the use of hydroskis as lifting devices has emphasized a need for information on the principal planing characteristics of prismatic surfaces at high attitudes with respect to the water surface, speeds, and wetted lengths. This information is needed for performance calculations, determination of hydrodynamic balance, and prediction of impact loads.

The hydrodynamic forces and centers of pressure on prismatic surfaces have been determined for ratios of the wetted length to beam up to 7, attitudes with respect to the water as high as 30°, and speed coefficients up to 25. Data for a flat plate are presented in NACA Technical Note 2981, and data for surfaces having 20° and 40° of dead rise are presented in Technical Note 2876. Since flare at the intersection of the bottom and sides of a planing surface (chine flare) is generally desirable for spray control and for recovery of lift lost by the use of dead rise, data also were obtained for 20° and 40° deadrise surfaces with horizontal chine flare. Data for these surfaces are presented in Technical Notes 2804 and 2842, respectively.

The results of these studies show that, during high-speed steady-state planing, the planing characteristics for a given trim depend primarily on the lift coefficient (lift divided by wetted area and dynamic pressure) rather than on speed and load. Increasing the angle of dead rise from 0° to 20° and from 0° to 40° resulted in average losses in lift coefficient of approximately 27 percent and 50 percent, respectively. With horizontal chine flare, these losses in lift were reduced to 15 percent and 30 percent, respectively. In general, the ratio of the center-of-pressure location forward of the trailing edge to mean wetted length decreased with increase in dead rise. Friction drag at high attitudes was negligible, and thus the drag may be assumed to be equal to the product of the load and the tangent of the attitude angle.

HELICOPTERS

Although much progress has been made, improvement in helicopter flying qualities continues to be an important matter. Better definition of design goals and methods of relating design changes to stability characteristics are essential. In addition to the basic single-rotor case for which work has been previously reported, other important types, such as the tandem configurations, require study.

An investigation of the lateral-directional flying qualities of a tandem-rotor helicopter in forward flight was undertaken to determine desirable goals for helicopter lateral-directional flying qualities and possible methods of achieving these goals. The results of this study are presented in Technical Note 2984. Pilot opinions are included to show what considerations are important insofar as flying qualities are concerned. The conclusions are also expressed in the form of desirable flying-qualities requirements.

As an aid to understanding and analyzing the stability of a tandem-rotor helicopter as well as a single-rotor machine, a study has been made at the Georgia Institute of Technology, under NACA sponsorship, of the normal component of induced velocity in the vicinity of a lifting rotor. The tables and charts in Technical Note

2912, which reports this study, may be used to determine the interference-induced velocities arising from the second rotor of a tandem or side-by-side rotor arrangement and the induced flow angle at a horizontal tail plane.

Conditions encountered by some rotors used in convertaplane designs do not permit certain simplifying assumptions used in analysis of the stability or performance of more conventional rotors. A study was conducted at the Georgia Institute of Technology, under NACA sponsorship, to develop a blade-element analysis for lifting rotors that would avoid the approximations that blade-element inflow angle and blade angle are small, and thus be useful for convertaplane calculations. The results of this study, presented in Technical Note 2656, are in agreement with experimental results previously reported in the range of rotor operating conditions encountered by helicopters.

An experimental investigation of some factors in the problem of reducing the descending velocity of a helicopter in autorotation was conducted by Princeton University, under NACA sponsorship, and is reported in Technical Note 2870. In this study, tests were made using a model rotor to examine the effects of disk loading, rotor inertia, and amount and rate of blade-pitch change on the flare performance of the rotor. The tests were extended to ranges of the variables which would be disastrous in flight.

In order to permit greater reliability without sacrifice of useful load, particularly for less conventional rotary-wing designs, a better understanding of the loads occurring in flight is essential. As one step, an analysis has been made of load factors obtained in flight tests of two single-rotor helicopters. Some additional information obtained from military-pilot-training and commercial-airmail operations with helicopters is also incorporated in this study, which is reported in Technical Note 2990. Load factors of the order of 2.5 were found to be attainable by several different deliberate maneuvers, and this same value was also approached under actual operating conditions. The largest flight loads, as a group, resulted from pull-ups in which both cyclic and collective control were applied with certain phasing. The assumption that flight load factors are limited to the value that would be computed by assuming all blade sections to be operating at maximum lift coefficient agreed well with flight-test results. This assumption thus provides a convenient method of estimating, for new designs, the maximum obtainable load factors for any given flight condition. It is concluded that higher speed helicopters and unorthodox configurations may be subjected to load factors materially higher than those experienced by current types.

The complex nature of the flow through a helicopter rotor, both in hovering and in forward flight, renders the prediction of aerodynamic loading on the blade very difficult. In order to provide insight into the nature and distribution of aerodynamic loading, pressure distributions were measured on a model helicopter rotor blade under hovering and simulated forward flight conditions. This study, carried out by the Massachusetts Institute of Technology under NACA sponsorship, is reported in Technical Note 2953. The work included tests of rotors with and without flapping-hinge offset. The results, showing loading distribution on the rotor disk, indicated a marked difference between the aerodynamic characteristics of the two rotors operating under identical conditions. The introduction of an appreciable amount of flapping-hinge offset resulted in a large first-harmonic aerodynamic loading in simulated forward flight. Blade-flapping measurements revealed appreciably lower values of first-harmonic flapping coefficients for the offset rotor as compared with the conventional configuration. An analysis of the angle of attack at the tip of the retreating blade, based on experimental flapping measurements, indicated that an appreciable offset flapping hinge in combination with a low blade mass constant offers a means of postponing stall on the retreating blade.

POWER PLANTS FOR AIRCRAFT

Since the achievement of supersonic flight, NACA research in the propulsion field has been intensified in obtaining greater power, better fuel economy, extended operating range of each engine component, reduction in engine weight and critical material content, and increased engine life. The results of research advanced in these areas have had a profound influence upon the future success of our military program. Today, the problems which require solution in these areas have become increasingly acute as demands for extended powerplant performance, dictated by practical supersonic flight, are made.

The high altitude and high Mach number propulsion research facilities at Lewis are the major research tools that permit an understanding of the extraordinarily difficult problems which are encountered in the supersonic propulsion system. They have made possible rapid research and development on advanced engines incorporating new basic research ideas. They have reduced the time to place into military service use those engines currently in the initial sea-level qualification test stage at manufacturers' plants.

In order to promote the early use of research results in the design and development of propulsion systems, the practice of holding technical conferences with representatives of the military services and the engine industry was continued during the past year. A technical conference on research advances in the turbojet engine for supersonic propulsion was held at the Lewis Laboratory.

In the following sections recent unclassified research for powerplants for aircraft is described.

AIRCRAFT FUELS

High-speed flight has increased the demands for greater power per pound of engine, per unit volume of engine, per pound of fuel, and per unit volume of fuel. Emphasis has therefore been placed on the development of special fuels that will materially increase the performance of a given aircraft by virtue of the fuel properties alone. In high-speed flight, fuels that provide higher thrust or fuels that reduce fuel weight or volume consumption, or both, are particularly desirable because they offer increases in aircraft speed and range.

In addition to the increased effort on specialized fuels, research on conventional fuels and hydrocarbon components of these fuels has been continued in order to more fully understand the effect of fuel structure on the various combustion parameters such as stability limits, ignition energy, combustion efficiency, and carbon and smoke formation.

Synthesis and Analysis

The synthesis and purification of cyclopropane hydrocarbons are begun at the Lewis Laboratory in 1946 in order to provide high-purity samples of substituted cyclopropanes for an investigation of the effect of molecular structure on combustion characteristics and other properties pertinent to research on fuels for aircraft propulsion systems. The research pertaining to the synthesis of 19 hydrocarbons and 14 nonhydrocarbon derivatives of cyclopropane is summarized in Report 1112.

Dicyclopropyl, the lowest-molecular-weight dicyclic hydrocarbon, was desired for an investigation of the effects of molecular structure on combustion characteristics and other properties pertinent to research on aircraft propulsion systems. Several methods are known for the preparation of hydrocarbons which contain one cyclopropyl ring, but a search of the literature when the present work was begun did not reveal any previous attempts to prepare a hydrocarbon which contained two cyclopropyl rings. The reaction of cyclopropyl chloride with lithium was investigated as a possible approach to the synthesis of dicyclopropyl.[1]

A synthesis of vinylcyclopropane was accomplished by the dehydration of methylcyclopropyl carbinol over alumina at temperatures between 265° and 300° C. and gave vinylcyclopropane in yields as high as 54 percent. By fractionating the hydrocarbon azeotropically with ethanol, vinylcyclopropane of high purity (99.9 mole percent) was obtained.[1]

The preparation of a series of cyclopropylalkenes and cyclopropylalkanes, in which the cyclopropyl ring was located in the 2-position of C_3, C_4, C_5, and C_6 straight chains, was recently reported. Similar reactions were reported for the preparation of a cyclopropylalkene and a cyclopropylalkane in which the cyclopropyl ring was located in the 2-position of a branched C_4 chain.[1]

The combustion process and burner-performance characteristics are ultimately the net function of physical and chemical properties of the fuel-oxidant mixture, and investigation of such fundamental fuel properties is now in progress. As a part of the overall program, the minimum energy required to ignite a fuel-air mixture was considered for investigation, not only because

[1] See Slabey paper listed on p. 52.

of its obvious implications in engine starting, but also because it may be directly related to the control of the entire combustion process. This investigation employed a controlled-duration capacitance spark as the igniting source for a quiescent combustible mixture contained in a small bomb. The minimum ignition energies for six hydrocarbon fuels are reported.

In recent research, one approach to the problem of understanding complex combustion processes in jet engines has been the study of systems under carefully controlled conditions. This approach has been used in a program to procure data on the fundamental properties of hydrocarbons which might be related to the performance of engine combustion chambers. Several phases of this program have already been published, including preliminary studies on flame speeds, minimum ignition energies, flammability limits, and quenching distances. An attempt was made to select an apparatus and a set of conditions which would yield a consistent set of reliable flammability limits. The flammability limits of 18 high-boiling hydrocarbons at reduced pressures were studied in a closed flame tube with hot-wire ignition. Characteristic two-lobe flammability limit curves were exhibited by all the hydrocarbon studies. The minimum pressure limit was not affected by the molecular weight. Correlations are presented relating the flammability limits to fuel properties.

In recent years considerable effort has been made to determine the factors and mechanisms which govern the formation of smoke during the burning of fuels, so that, eventually, methods of controlling smoke formation can be devised. Particular emphasis has been placed on the problem of preventing smoke formation during the burning of fuels in combustion chambers. Since the type of hydrocarbon present in a fuel is known to effect smoke formation, an investigation was conducted as part of the fundamental combustion program to determine the maximum rate at which various pure hydrocarbons could be burned without producing smoke. From this investigation, it was hoped that the effects on smoking of such variables as chain length, chain branching, degree of unsaturation, position of unsaturation, and ring size could be evaluated and an explanation found to account for the variations. The variations in smoking tendency among 38 gaseous and liquid pure hydrocarbon compounds when burned as diffusion flames in still air were determined.

A recent report presents the results of an analysis of the smoke and carbon obtained from turbojet-engine combustors. The characteristics of various types of carbon formation and methods of analysis which can be used to determine the various types of fuel residue are discussed. The analytical methods used were electron microscopy, carbon-hydrogen determinations in a combustion train, and X-ray diffraction. Described also were the structures and probable methods of formation for turbojet smoke and the carbon deposits found on the dome and walls of the turbojet-combustor liners.

COMBUSTION

Fundamentals of Combustion

An investigation was performed to determine how the smoking properties of a given fuel are modified by changes in several of the variables associated with the burning of the fuel in a combustion chamber. Variations in initial gas temperature, fuel-flow rate, secondary-air-flow rate, and burner-tube diameter were studied. Fuel-air ratios were measured both at the appearance of the first evidence of carbon formation in the flame, and at the point where smoke issued from the flame. Of all the variables studied, temperature alone affected the fuel-air ratio at which the first evidence of carbon formation was visible in the flame.

It is of interest to know how these variables affect the initial formation and assimilation of smoke in a flame, for if smoke formation could be controlled in the primary flame reaction zone of a combustion chamber, the problem of burning smoke in the later stages of the combustion process would not exist.

Flame velocity by the soap-bubble method is calculated from the rate of growth of the flame sphere radius, which should be uniform, divided by the expansion ratio of the gas mixture. New work with the soap-bubble method has shown that methane in some oxygen-enriched air atmospheres and in pure oxygen at the concentration for maximum flame velocity (near stoichiometric) does not give a smoothly propagating flame. An irregular flame front develops, accompanied by an increase in the rate of flame growth.

A study of the effect of oxygen concentration on the flame velocity of isooctane-oxygen-nitrogen mixtures showed that flame velocity increased linearly with the mole fraction of oxygen. This linear relation was shown to be at variance with the predictions of the approximate solutions of two theoretical equations, one based on a thermal and the other based on a diffusion mechanism of flame propagation, either of which predicted a decreasing rate of change of flame velocity with increasing oxygen concentration. Data on the effects of the equivalence ratio and initial temperature on flame velocity have been obtained for propane and ethylene-air mixtures.

The ability to predict the flame velocities of fuels is of importance in the field of aircraft propulsion. A correlation has been found between combustion efficiency of a ram-jet burner and the laminar flame velocity of the fuel. The prediction of flame velocities is difficult for three reasons: (1) There is no complete, rigorous theory which can be readily applied; (2) there are no data on the kinetics of the oxidation process under flame conditions and very few data on transport properties at high temperatures; and (3) different methods of flame-velocity measurement give different values. It is therefore difficult to compare data from different sources. The uncertainty in measurements made by a given method is of the order of 5 percent. Flame-velocity measurements for different hydrocarbons, different initial temperatures, and different compositions were used with semitheoretical and empirical methods of flame-velocity predictions to show the correspondence between the measured velocities and the predicted velocities.

Research is being conducted to study the fundamental variables affecting the ignition and the combustion of fuel-air mixtures. As part of this research, the parameters which may influence the energy required for a spark to ignite homogeneous fuel-air mixtures are being investigated. One investigation was concerned with the effect of turbulence, generated by different sizes of wire grid, on the minimum spark-ignition energy of a flowing propane-air mixture. The required ignition energy increased with the wire size of the turbulence promotor and with the gas velocity, and decreased with the distance from the promoter to the spark electrodes. The required ignition energy therefore increased with those factors that are reported to generate increased intensity of turbulence.

A study has been made obtain quantitative data on the oxidation intermediates leading to the spontaneous ignition of hydrocarbon-air mixtures. Data were obtained for isooctane- and for n-heptane-air mixtures. Marked differences in the oxidation behavior of these hydrocarbons were noted and interpreted. A preliminary comparison of the oxidation of isobutane and of 2,2,5 trimethylhexane was also made (Technical Note 2958).

There is considerable interest in heat transfer and momentum transfer for bodies submerged in a flowing fluid. These transfers occur frequently in engineering operations and may be important in combustion chambers. Heat transfer coefficients for a spherical particle heated by an induction coil in a moving air stream were determined. A comparison of the experimental values with the theoretical values for heat transfer coefficients was made and an empirical relation between the heat transfer factor and the total drag coefficient was also suggested (Technical Note 2867).

Combustion-Chamber Research

In the field of jet-engine combustor research, burner instabilities are frequently encountered. In most cases a given combustor that exhibits one or more of these instabilities can be modified by a number of trial-and-error methods and the instabilities eliminated within the operating conditions. For example, "squealing" in afterburners is subdued by increasing the fluid velocity. Any of these instabilities can be extremely detrimental to engine performance. Types of burner instability are enumerated and the role of standing waves in burners are discussed in Technical Note 2772. The status of the problem of flame-driven standing waves is reviewed and a one-dimensional flow theory giving the mechanism whereby a flame drives or damps a standing wave is presented. In this theory, the reflection, transmission, and amplification of waves passing through a flame region were determined from the continuity and momentum equation.

The design of high-output combustors for jet-propelled aircraft and of other industrial equipment may be aided by an accurate knowledge of liquid vaporization rates. According to the type of equipment, the liquid may evaporate from spheres, cylinders, or flat surfaces. In jet engines, the fuel is frequently injected as liquid droplets at a point upstream of the combustion zone, and the concentration of vaporized fuel in the fuel-air stream entering the zone is determined by the rate of evaporation of the droplets. To determine this evaporation rate, vaporization-rate data and surface-temperature data were obtained for nine pure liquids evaporating from the surface of a porous sphere under conditions similar to those encountered in aircraft combustion systems.[2]

Numerous investigations have been made to determine the effect of pressure on the vaporization rate of droplets in still air. However, vaporization-rate data, which show the effect of pressure on the evaporation rate of drops in streams of air or other gases, are unavailable. Since a range of combustion-chamber pressures may be encountered in the operation of jet engines, the effect of air-stream pressure on the vaporization rate of fuel droplets may be of importance in the study of combustible fuel vapor and air mixtures for jet combustors. In order to determine the effect of pressure on vaporization rate in air streams, a range of pressure conditions encountered in aircraft combustion systems was studied (Technical Note 2850).

One of the processes in a jet-engine combustor is the exchange of radiant energy among the fuel-oxidant-flame components, combustor walls, and combustion products. A better understanding of the nature of the involved radiative processes may supply information that is useful for combustor design and for fuel specifications. The radiative processes involved in combustion were investigated to determine the present role of radiant energy transfer in combustors. It was shown that, at present, the amount of radiant energy transfer

[2] See Ingebo paper listed on p. 52.

from flame to fuel is quite small in a turbojet combustor. Methods of increasing the equivalent gray-body emissivities of the fuel drops and the flame, as well as the efficiency of the energy transfer itself, were examined.

LUBRICATION AND WEAR

Fundamentals of Friction and Wear

Of the known synthetic fluids, silicones have the best viscosity-temperature properties for lubricants in turbine engines. The principal characteristic that has limited consideration of silicones as lubricants for turbine engines has been that they are poor boundary lubricants for ferrous surfaces. The behavior of silicone lubricants in boundary lubrication of ferrous surfaces was studied in Technical Note 2788. In these studies a hypothesis was advanced which considered that solvents would influence the lubricating ability of silicones by affecting the molecular arrangement at the fluid-surface interface. The data obtained (with solutions of solvents blended with silicones) are considered substantiating evidence for this hypothesis. The solutions reduced friction and prevented surface failure even when the solvent as well as the silicone, was an extremely poor lubricant. Solutions of silicones and diesters were suggested as possible "practical" lubricants for current aircraft turbine engines. It was felt that this combination would provide practical low-volatility lubricants that might have viscometric properties approaching those of the pure silicone and that it would provide effective lubrication resulting from a possible solvent effect of the diesters.

Boundary lubrication and friction data on synthetic fluids in general are very limited, therefore, the lubricating effectiveness of a number of synthetic fluids was studied at high sliding velocities (Technical Note 2846). Sliding friction data and surface failure properties show that a number of synthetics, including diesters, polyethers, a silicate ester, and a phosphonate ester, as well as a silicone-diester blend, are more effective boundary lubricants at high sliding velocities than comparable petroleum oils. A silicone-diester blend, an alkyl silicate ester, and a compound diester (containing lubrication additives) were more effective boundary lubricants at high sliding velocities than the diester from which the most widely accepted synthetic lubricants are made. A diester failed to lubricate nonreactive surfaces, which indicates that the lubrication mechanism for diesters may involve chemical reaction with the lubricated surfaces.

Because of the high operating temperatures of new and projected turbine engines, an experimental study (Technical Note 2940) was conducted to learn the effect of high lubricant bulk temperatures on the boundary lubricating effectiveness of various types of synthetic fluids. In general, under the conditions of these experiments, the upper limit of temperature for effective lubrication (effective lubrication is defined as the region where low friction coefficient is obtained and no surface damage results) was greater for synthetic lubricants than for a petroleum lubricant of similar viscosity at 100° F. The experimental results tend to substantiate the hypothesis that lubrication with esters (and possibly other fluids) results from formation of an absorbed metal soap film by free acids in the lubricants. Since oxide films are important both to soap formation and to lubrication, failure may be caused by: (1) Failure of the soap film (by melting or decomposition), or (2) failure of the lubricant to maintain the metal soap or oxide films, or both, on the surface. It appears that bulk-fluid-failure temperature is limited by either of these lubrication-failure mechanisms through the effect of temperature on the thermal stability of the bulk fluid. Thermal stability can be associated with viscosity grade within a given class. At temperatures up to its decomposition point, a silicate ester showed more promise than other lubricants studied. The phosphonate esters decomposed at high temperatures to form products that are corrosive to steel, but which prevent complete lubrication failure.

Contract research at the University of Cincinnati has been concerned with determining the spontaneous ignition temperature of organic compounds with particular emphasis on lubricants. Lubricants are known to have low ignition temperatures and, consequently, may be the source of many aircraft fires. Technical Note 2549 gives ignition temperature data for 50 pure organic compounds including paraffins, olefins, aromatic hydrocarbons, ethers, alcohols, and esters. The data indicate those molecular structural features that result in high ignition temperatures. Technical Note 2848 presents ignition data on available petroleum and synthetic lubricants and also compounds synthesized to incorporate favorable structural features reported in Technical Note 2549.

Fretting Corrosion

The minimization of the start and intensity of fretting is a pressing problem in many aircraft engine components such as bearings, bearing housing, spline shaft, and other couplings. Inasmuch as a bonded film of molybdenum disulfide (MoS_2) showed promise in delaying the occurrence of fretting, an investigation was conducted of the bonding of MoS_2 to various materials to form a solid lubricating film (Technical Note 2802). This investigation had as objectives: (1) The determination of practical methods of bonding MoS_2 to various materals, and (2) friction and endurance characteristics of films so formed. The results indicated that satisfactory solid-film lubricants can be formed on a variety of materials by brushing on the solid lubricant mixed with a resin-forming vehicle. Under baking conditions, the liquid vehicle decomposes or polymerizes to a resin which binds the particles of MoS_2 together and to the surface to be lubricated. The choice of the resin-forming vehicle is governed by the types of application. In the use of asphalt-base varnish, for example, cleaning of the specimens was not critical because of mutual solubility of the varnish and thinner and the usual surface contaminants. Friction and endurance data obtained under severe conditions of high-sliding velocities and high surfaces stress show that solid lubricant films (between 0.0002 and 0.0005 inch thick) of MoS_2 bonded with the various resins resulted in good lubricating effectiveness.

Bearing Research

Because of the lack of information in the field, an experimental investigation (Technical Note 2841) was conducted to determine the performance characteristics of deep-groove ball bearings under radial load at high speeds. The results indicated that bearing operating temperatures were most sensitive to changes in speed and to distribution of the cooling oil. The effectiveness of lubrication depended on the quantity of oil transmitted through the bearings regardless of the method of supplying oil. At low speed, neither load nor oil flow had any appreciable effect on bearing operating temperatures.

Since a large number of present bearing failures of gas turbine engines and other high-speed bearing applications have been attributed to cage failures, it was felt a roller bearing without a cage might eliminate the source of trouble. In accordance, an investigation was conducted of conventional and special designs of cageless roller bearings at high speeds. Preliminary results at high speeds, however, indicate the greater reliability of the conventional cage-type roller bearing over the cageless roller bearing, although the cageless roller bearing may have promise under certain conditions.[3]

NACA sponsored research on journal bearings at Cornell University resulted in the publication of Technical Notes 2808 and 2809. Technical Note 2808 is an analytical development of a mathematical expression that can be used to predict the circumferential and axial pressure distribution in a short journal bearing. Technical Note 2809 is an experimental investigation that included the effects of bearing length, speed, load, and lubricant viscosity. The theoretical expression derived in Technical Note 2808 agrees favorably with experimental results obtained in Technical Note 2809.

[3] See Macks, Nemeth, and Anderson paper listed on p. 52.

COMPRESSORS AND TURBINES

Compressor Research

Compressor component research is aimed at development of compact, light-weight, efficient machines for application to aircraft propulsion systems. Theoretical and experimental studies of design limitations and flow processes are made throughout the broad operating range required for high-speed high-altitude aircraft applications in order to develop and evaluate design techniques. This research covers a wide field of axial-flow and centrifugal compressor types.

Because of compressibility effects, the stages of a high-pressure-ratio, multistage, axial-flow compressor can be properly matched at only one condition of aerodynamic speed and weight flow. The operational requirement for high-altitude high-speed flight requires operation of the compressor at low aerodynamic speeds. High-altitude climb utilizing full rated engine output, requires operation at high aerodynamic speeds. Detailed studies of a number of commercial and experimental high-pressure-ratio compressors have been made to study the effects of stage mismatching which result from these aerodynamic speed variations.

As a multistage compressor operates over a wide range of aerodynamic speeds, one or more individual stages may be expected to stall.

The flow condition defined as stall in single-stage compressors, is characterized by zones of high and low flow which rotate about the compressor axis in the direction of the rotor hub at a lower speed. These rotating stalls may be classed as either progressive stall, with multiple stall zones at the blade tip, or root-to-tip stall.

An analysis of a hypothetical compressor, with front stages having a progressive-type rotating stall and with middle and latter stages having the pressure-ratio discontinuities associated with root-to-tip stall, indicates multistage compressor performance with discontinuities in pressure-ratio weight-flow characteristics at all speeds. At low speeds, these discontinuities result from stall of the earliest stages having discontinuous characteristics, and at high speed from stall of the latter stages. The resulting discontinuities in the compressor performance map introduce problems of starting and accelerating the engine to design speed and may also cause steady-state operating problems at cruise and high-altitude flight conditions.[4] Rotating stall may also be a potential source of vibrational excitation in multistage axial-flow compressors.

Flow-visualization techniques were employed in experimental investigations of flow processes to ascertain

[4] See Huppert and Benser paper listed on p. 52.

the streamline patterns of the secondary flows in the boundary layers of cascades and thereby provide a basis for more extended analyses in turbomachines. The three-dimensional deflection of the end-wall boundary layer resulted in the formation of a vortex well up in each cascade passage. The size and tightness of the vortex generated depended upon the main flow turning in the cascade passage. Once formed, a vortex resists turning in subsequent blade rows. This results in unfavorable angles of attack and possible flow disturbances in subsequent blade rows.

Two major tip-clearance effects were observed: the formation of a tip clearance vortex and the scraping effect of a blade with relative motion past the wall boundary layer. The flow patterns indicate possible methods for improving the blade-tip loading characteristics of compressors and of low- and high-speed turbines (Technical Note 2947).

The method that was developed for predicting the steady flow process of a nonviscous compressible fluid along a stream surface between two adjacent blades was applied to a single-stage and a seven-stage axial-flow compressor (Technical Note 2961). The inlet stages, designed with a symmetrical velocity diagram at all radii, showed large radial flows as a result of the radially increasing angular momentum associated with this type of diagram. The radial distributions obtained were closely approximated by a simplified solution given in Report 955. Three-dimensional solutions have been made for rotating axial-flow passages bounded by straight blades of finite axial length. These solutions indicated that the deviation of the flow direction from the assumed orientation in two-dimensional solutions is small for typical axial-flow blade rows (Technical Note 2834).

Experimental and theoretical research was continued to explore the potentials of supersonic-type compressors. The method of characteristic coordinates was employed in obtaining a solution for the flow between blades of supersonic compressors (Technical Note 2768).

Theoretical analysis and experimental studies have been made in order to improve flow capacities and efficiencies of mixed-flow impellers and diffusers. A general design method was developed whereby two-dimensional channels could be designed to give prescribed velocity distributions.

A technique was developed and solutions for several through flow rates were made for nonviscous, three-dimensional potential flow in a rotating centrifugal-impeller passage. Comparison of these solutions with two-dimensional solutions showed that, for the type of geometry investigated, two-dimensional solutions can be combined to describe the three-dimensional flow in rotating impellers with sufficient accuracy for general engineering analysis (Technical Note 2806).

A summary of some of the results obtained in theoretical and experimental research on centrifugal compressors has been compiled. This summary includes impeller and diffuser research as well as considerations of the general aspects of the application of centrifugal compressors to gas-turbine-type engines.

Turbine Research

Turbine research is being directed toward improved general performance and the development of means by which optimum designs can be selected for any specific application. It consists of theoretical areodynamic studies, two- and three-dimensional cascade investigations, and single and multistage turbine research.

A rapid method for the determination of turbine-stage velocity diagrams within specified aerodynamic limits was developed. The method facilitates the selection of the number of turbine stages, the determination of the necessary proximity of staging operation to design limits, and the selection of the optimum work division between or among the stages for any given application (Technical Note 2905).

Further insight into the characteristics of highly loaded turbine stages was gained by an analysis of choked-flow turbines. This analysis indicated that the area ratios and equivalent blade speeds are the controlling factors in the design and operation of such turbines. For the usual class of turbines, increasing the equivalent blade speed of a given stage makes the internal flow conditions less critical. Six criteria are stated that will aid in establishing, from test data of multistage turbines, which blade rows are choked and which are not (Technical Note 2810).

In order to increase understanding of the origin of losses in a turbine, the secondary-flow components in the boundary layers and blade wakes of an annular cascade of turbine nozzle blades were investigated. A detailed study was made (Technical Notes 2871 and 2909) of the total-pressure contours and of the inner-wall loss cores downstream of the blades.

The inner-wall loss core associated with a blade of the turbine-nozzle cascade is largely the accumulation of low-energy fluids originating elsewhere in the cascade. This accumulation is effected by the secondary-flow mechanism which acts to transport the low-energy fluids across the channels on the walls and radially in the blade wakes and boundary layers. At one flow condition investigated, the radial transport of low-energy fluid accounted for as much as 65 percent of the inner-wall loss core.

Turbine Cooling

Better turbine performance and the reduction of critical material content are important to continued improvement of the turbojet engine. Better turbine performance is obtained by operation at higher turbine-inlet gas temperatures which results in higher thermal efficiency and higher net output. These, in turn, have a major bearing on other performance factors such as turbine size, weight, and specific fuel consumption. Since the turbine-inlet gas temperature is limited to a value which will result in a reasonable life of the turbine blades and other highly stressed members, adequate cooling of these turbine parts will permit operation at the higher gas temperatures desired.

To provide fundamental heat-transfer data through which cooled blade design may be aided, an investigation was conducted to study free-convection heat transfer in a stationary air-filled heated tube. This investigation was extended to obtain heat-transfer data under turbulent mixed-, free-, and forced-convection flow conditions similar to those encountered in cooled turbine blades. The heat-transfer limits for each type of flow were established and expressed in correlation equations (Technical Note 2974).

Revised solutions of the laminar-boundary-layer equations for cases which involved cooling at the wall combined with large pressure gradients in the main stream produced specific-weight-flow profiles which locally exceed free-stream values. Heat-transfer and friction coefficients, boundary-layer thicknesses, and velocity, temperature, and specific-weight-flow distributions resulting from the revised solutions are presented for Euler numbers of 0.5 and 1.0, stream-to-wall temperature ratios of 2 and 4, and cooling-air flow rates through porous walls designated by flow parameters of 0, -0.5, and -1 (Technical Note 2800).

An investigation has been made in Technical Note 2863 of natural convection flow for a simplified but representative case, namely the flow with and without heat sources between two long parallel plates at constant temperatures oriented parallel to the direction of the generating body force. It is found that the flow and heat transfer, in general, not only are functions of the Prandtl and Grashof numbers but also depend on a new dimensionless parameter. If this parameter is not negligibly small, the compression work and frictional heating may appreciably affect heat transfer by natural convection.

Measurements of average heat-transfer and friction factors were obtained for air flowing through a smooth, electrically heated tube with a bellmouth entrance and a length-to-diameter ratio of 15 for a range of average surface temperatures from 875° to 1735° R. and corresponding surface-to-bulk temperature ratios from 1.6 to 2.8, Reynolds numbers from 2,200 to 300,000, and heat fluxes up to 230,000 Btu per hour per square foot of heat-transfer area. The data of this investigation correlated with data obtained in previous investigations with longer tubes on the basis that the heat-transfer coefficient varies as the -0.1 power of the length-to-diameter ratio. No effect of the length-to-diameter ratio was observed on the average friction factor.

An experimental investigation of the forced-convection heat-transfer characteristics of sodium hydroxide was made for a range of Reynolds numbers from 5,300 to 30,000, corresponding to velocities from 3.8 to 15.4 feet per second, average fluid temperatures up to 938° F., and heat-flux densities up to 226,000 Btu per hour per square foot, for both heating and cooling. Data were also obtained from the same apparatus for both water and an aqueous solution of sodium hydroxide. The results showed that sodium hydroxide heating data can be correlated by the Nusselt relation, and that the data fall slightly above the McAdams correlation line. The cooling data are, however, fairly well represented by the McAdams correlation line.

The heat transfer and fluid friction were analyzed for fully developed turbulent flow of supercritical water with variable properties in a smooth tube. A previous analysis of turbulent flow and heat transfer for air with variable properties flowing in a smooth tube is generalized in order to make it applicable to supercritical water. The generalization is necessary because all the pertinent properties of supercritical water vary markedly with temperature. The effect of variation of fluid properties across the tube on the Nusselt number and friction factor correlations can be eliminated by evaluating the properties at a reference temperature which is a function of both the wall temperature and the ratio of wall-to-bulk temperatures.

ENGINE PERFORMANCE AND OPERATION

Performance and Operating Characteristics

The problems associated with the evaluation of full scale engine performance as well as flow fluctuations within the engine are of such a nature that a knowledge of the instantaneous flow patterns is of considerable importance. The use of hot-wire anemometers is a means of obtaining this information. The results of a study of flow through compressors and burners, with the aid of hot-wire anemometers, are reported in Technical Note 2843.

The general class of unsteady flow problems is currently of increasing interest particularly in connection with stability in high speed combustion processes and the overall effects on engine performance. The effect of a shock passing through a flow field (or vice versa) is likely to be important in many applications. The propagation of a plane normal shock wave through a gas at rest as modified by the influence of a weak pattern of unsteady disturbance is described in Technical Note 2879. The disturbances considered are a plane sound wave and a convected plane vorticity wave. Since sound waves may impinge on a shock either from upstream or downstream, both cases are considered.

Afterburners and Jet Exits

In wind-tunnel testing of engines the exhaust gases of the engine mix with the tunnel air. The effect of such a mixing upon the total pressure and Mach number of the combined streams is of importance for obtaining correct engine performance results. Further, accurate determination of tunnel power requirements can be made, once the effects of jet mixing on power requirement is understood. A one-dimensional flow analysis of the results of parallel-jet mixing is presented in Technical Note 2918, where the area of the streams after mixing is equal to the sum of the areas of the two streams being mixed. Changes due to burning of excess fuel downstream of the engine-exhaust station are also considered.

The results of an experimental investigation to determine the temperature profile downstream of heated air jet directed at various angles to an air stream have been incorporated in Technical Note 2855.

An increase in jet thrust over that achieved with a sonic outlet can be realized by complete expansion of the exhaust gases in a convergent-divergent nozzle. In the calculation of this process and in the evaluation of experimental nozzle data, the flow process in the nozzle is usually assumed to be adiabatic. However, for nozzles located directly downstream of combustion chambers, such as in jet powerplants, heat may be released to the working fluid during the expansion process in the divergent portion of the nozzle. Technical Note 2938 contains an analytical treatment of heat addition to a divergent stream with initially sonic flow which permits evaluation of the effect of delayed combustion on convergent-divergent nozzle performance. The analysis indicates that nozzle heat addition delays nozzle over expansion and affects the jet thrust appreciably.

Research Techniques

An investigation was conducted to determine the increase in the useful ranges of simulated flight conditions that may be obtained with a given jet-engine research facility when the choked-exhaust-nozzle technique, or exhaust jet diffuser, or both are employed. The results of this investigation describe the two methods, present the considerations involved in their application, and give typical results of their use as well as confirmation of the accuracy of the data obtained by utilization of these techniques.

Errors in the measurement of jet-engine gas temperature by thermocouples have been analyzed. Based on this analysis, design criteria of thermocouple probes have been developed.[5]

The mechanized data-handling system currently used at the Lewis laboratory consists of engine instrumentation, digital pressure and temperature-recording instruments, tape-to-card conversion machinery, punch-card operated electronic calculator, and associated card handling equipment.[6]

A method of recording multiple pressures in digital form has been developed in which pressures are converted to the digital form at the primary transducer and subsequently handled in a numerical form.[7]

A 72-channel automatic potentiometer has been developed and put into service. This apparatus, which measures voltages in the ranges 0 to 10 and 0 to 40 millivolts to an accuracy of 0.25 percent at a speed of 1½ readings per second and records the information on a punched tape, is described in a current journal paper.[8]

An investigation has been conducted to provide a basis for the design of air-flow combination probes intended to survey static and total pressure, and direction of flow, with special reference to subsonic turbomachine testing. Static-pressure probes, yaw-element probes, claw-type probes, and combination probes were tested. From the results of this investigation, reported in Technical Note 2830, the factors which determine the sensitivity of claw-type yaw probes were determined. Satisfactory combination survey probes for sensing static and total pressure and direction of flow in one or two planes were devised.

POWERPLANT CONTROLS

Engine controls research is directed towards defining the dynamic characteristics of the various powerplants (turbojet, ramjet, and turbine-propeller) as well as developing a control theory for engine control application.

A modification of Winer's filter theory and an application to the choice of an optimum control in a closed-loop system is described in Technical Note 2939. The approach used is applicable to all closed-loop systems, and provides an optimum control in an environment of random disturbances. The theory is particularly useful in commonly encountered situations where the environment of disturbance cannot be predicted in detail, and where the penalty in performance resulting from generous margins of safety is great.

A method for predicting the performance of hydraulic servomotors is presented in Technical Note 2767. Experimental data confirmed the theory for

[5] See Scadron, Warshawsky, and Gettleman paper listed on p. 52.
[6] See Rawlings paper listed on p. 52.
[7] See Sharp, Coss and Jaffe paper listed on p. 52.
[8] See Smith paper listed on p. 52.

servomotors in which the volume of hydraulic fluid was kept low. Servomotor design criteria derived from the theory were presented by Gold at an A. S. M. E. meeting on April 28–30, 1953.

HEAT-RESISTING MATERIALS

High Temperature Materials

The practical application of high-temperature alloys requires that a considerable amount of background information be obtained on the particular combinations of alloying elements under consideration. It is usually desirable to start with a determination of the necessary phase and equilibrium diagrams and then proceed to study variations in physical properties produced by small changes in chemistry, the effect of processing variables on final physical properties, and finally the actual performance of the alloy in the desired end application.

Studies have been conducted of portions of the iron-nickel-molybdenum and the iron-molybdenum-cobalt ternary systems at 2200° F. with emphasis placed on the face-centered cubic solid solution sections of the diagrams (Technical Note 2896). This work completed the program established at the University of Notre Dame, under NACA sponsorship, which has been reported previously. The phases occurring in the above-mentioned systems were identified by means of X-ray diffraction and by etching methods. The phase boundaries at 2200° F. were determined microscopically, using the disappearing phase method with quenched specimens. A total of 170 alloys was investigated. Of these, 8 were common to both of the systems, 105 were in the iron-molybdenum-nickel system, and 57 were in the cobalt-iron-molybdenum system.

Once the fundamental relationships in a desired alloy system are determined, it then becomes desirable to determine, insofar as possible, the influence of small changes in chemical composition on the properties of the heat-resistant alloys developed. In most high-temperature alloys, some uncertainty exists regarding the restrictions on the composition limits as used in commercial practice and the fundamental mechanisms by which the composition influences properties. For these reasons, an investigation was undertaken at the University of Michigan, under NACA sponsorship, for the purpose of providing systematic data for compositional variations in forged alloys stemming from a nominal composition of 20% chromium, 20% nickel, 20% cobalt, 3% molybdenum, 2% tungsten, and 1% columbium (Technical Note 2745). Inasmuch as processing variables (such as melting practice, forging practice, and final heat treatment) also control strength properties, every effort was made to minimize the effects of these variables. It appears that all of the alloying elements can be varied individually between quite wide limits without significantly changing the rupture properties. This could be partially responsible for the difficulty in correlating chemical composition with physical properties at high temperatures from available data. There was no evidence to indicate that a composition variation, within the usual commercial limits, contributes materially to scatter bands in physical properties.

One of the newer materials of interest for high-temperature applications is molybdenum. This material is made commercially by both powder-sintering and arc-casting methods. Considerable data are now available on the mechanical properties of molybdenum produced by both methods, but unfortunately these data are in many instances contradictory and not reproducible. So-called ductile molybdenum is made by both methods, but frequently the ductility is low or absent. This variation in ductility at room temperature is of great interest if molybdenum is to be used in load-bearing applications. In view of this, an investigation was conducted to determine the effect of prior swaging on the transition temperature, with the objective of producing a ductile material at or near room temperature (Technical Note 2915). The material studied was sintered, wrought molybdenum, with the amount of swaging, recrystallization temperature, and stress relieving factors as the variables studied. As was expected, an increase in swaging progressively lowered the transition temperature by a maximum of 100° F. This effect of swaging is lost when molybdenum is recrystallized. No relationship could be established between the grain size of recrystallized metal and strength and ductility within the transition temperature range. However, above the transition range, for example at 200° F., the ductility increased with decreasing grain size.

Although previous research indicates that swaging increases the strength and ductility of molybdenum, it also has a detrimental effect of lowering the recrystallization temperature. This limits the use of molybdenum to less than 2000° F. and prevents brazing or the application of protective coatings at high temperatures which would recrystallize the metal. Accordingly, an investigation was undertaken to determine whether molybdenum could be produced by a slight modification of commercial fabrication methods which would have a higher recrystallization temperature without an appreciable sacrifice in strength or ductility (Technical Note 2973). The results obtained were not clear-cut since different batches of material responded in different fashions. For instance, the one-hour recrystallization temperature of one lot of metal ranged from above 2900° F. to 2300° F. for 35% to 99% swaging, whereas another two lots of metal had a constant recrystallization temperature of approximately 2075° F.

over the entire working range of 10 to 99%. No difference was detected by either chemical or X-ray diffraction analyses which might account for this variation among lots. Another interesting result was that the atmosphere used to determine the recrystallization data had a pronounced effect on the recrystallization temperature of one lot of molybdenum. This material, swaged 50%, recrystallized in one hour at 2850° F. in argon, at 2750° F. in vacuum, and at 2300° F. in hydrogen. In the same atmospheres, the recrystallization temperature of the other two batches of material, swaged 99%, varied only from 2200° F. to 2300° F.

The actual application of a high temperature alloy usually results in a number of problems which can be traced back to the processing techniques. For instance, the uniformity of life of cast alloy gas-turbine blades is generally considered unsatisfactory. This lack of uniformity results in short times to initial blade failure compared to average life and does not permit the maximum use of the potential performance of the material. Previous studies of the effects of heat treatment upon uniformity of life of small cast AMS 5385 gas-turbine blades indicate that slight, if any, improvement is obtainable in this manner. A more effective method of influencing blade life uniformity might be through the control of blade grain size. Accordingly, an investigation was conducted to compare the uniformity of life and the initial failure time of groups of experimentally cast AMS 5385 blades of several grain sizes. The second objective was to relate the individual blade life to grain size of the experimentally cast blades. The grain size was varied from 4 to 11,200 grains per blade cross-section area (0.035 square inch) and was achieved primarily by variation in pouring temperature. A total of 90 blades were investigated at a temperature of 1450° F. and a stress of 19,000 psi at the midspan of the blade. A correlation was found to exist between the number of grains per blade cross-section and blade life; usually longer life was associated with the coarser grain sizes. The coarse grain blades studied had an improved uniformity in regard to initial failure time, but lower mean life than a group of commercially cast coarse grain blades.

As a continuation of the National Bureau of Standards' investigation, under NACA sponsorship, of the mechanisms of adherence of ceramic coatings to metals, a study was made of the gases evolved during the firing of vitreous coatings (Technical Note 2865). Previous investigations have shown that hydrogen is one of the gases evolved in the firing process and it was suspected that carbon monoxide might also be present. The results showed that the principle gases produced were carbon monoxide, hydrogen, and carbon dioxide. The blistering that is often observed in the early stage of firing when vitreous coatings are applied to low-carbon steel was found to be caused by evolution of the carbon gases formed by oxidation of the carbon in the steel.

A second portion of the National Bureau of Standards' program included an investigation of the relation between the roughness of the enamel-metal interface and the adherence of the enamel to steel (Technical Note 2934). One of the first explanations advanced for the adherence of vitreous base coats to steel was that of mechanical gripping. This hypothesis is based on the observation that when adherence is good there is usually a rough interface between the coating and the metal. The coating is thought to penetrate into the cavities or undercuts in the metal surfaces and when the coating hardens on cooling, the two materials are interlocked and thus mechanically bonded. Variations in adherence were produced by varying the amount of the metallic-oxide addition in the frit, by varying the surface roughness of the metal before application of the enamel, and by varying the firing time. It appears that there is a positive correlation between the adherence of a porcelain-enamel ground coat and the roughness of the interface. Most of the roughness which was associated with good adherence between the ground coat and the steel, developed during the firing process. Further results indicate that the roughness of the interface is necessary, but is not completely responsible for the development of good adherence.

The previous investigation concluded that roughness of the interface between an enamel and steel is an important factor in contributing to adherence. A theory was developed to explain one way in which this roughness might be produced by an electrolytic reaction between the cobalt in the enamel and the iron in the steel during the firing process (Technical Note 2935). It appears that cobalt, originally present as cobaltic-oxide in the enamel, plates out on the steel during a normal firing operation. Inasmuch as the molten enamel is an electrolyte, the mechanism involved appears to be one of a tiny galvanic cell in which the iron acts as the anode and the cobalt-plated area as the cathode. Corrosion, which is produced by galvanic attack on the iron, produces the desired surface roughness.

One phase of the problem of developing improved high-temperature alloys is the effort to gain a more detailed understanding of the nature of creep in metals. This is of importance in that almost all high-temperature alloys are designed to operate under conditions in which they will creep or stretch a definite amount in a certain time. In other words, most high temperature alloy parts are designed to fail in a finite time, usually after several thousands of hours of operation, although in special cases, such as in turbine blades, it is usually nearer 500 hours. Consequently, an understanding of how the creep process takes place and the metallurgical factors which affect it are of importance. It has been known for some time that creep is a complex process and that, among other complications, displacement sometimes occurs along grain boundaries of metals at the same time that the grains themselves are deforming. An investigation was undertaken by the Carnegie Institute of Technology, under NACA sponsorship, to isolate and examine grain boundary displacement (Technical Note 2746). The material studied was pure aluminum, under stresses of 1 to 100 psi and temperatures from 400° F. to 1,200° F. The specimens were bicrystals pulled in tension. It was found that displacement occurs in a cyclic fashion, increasing directly with the temperature at the beginning of the cycle but subsequently obeying a chemical-rate law with a computed activation energy of 9,700 calories per mole. There is, for each temperature, a threshold stress below which displacement does not occur. A substantial thickness of crystalline metal participates in the gliding motion and becomes fragmented and extensively disoriented in the process.

Stresses Research

The subject of extrapolation of creep and stress-rupture data on materials at high temperature is of considerable current interest, particularly for applications in gas turbines. Because extensive testing cannot be conducted on all these materials, an extrapolation procedure materially assists in the identification of the more promising materials. An analysis was conducted which resulted in a parameter that yielded improved accuracy over similar extrapolation procedures (Technical Note 2890). The value of this parameter was determined in an investigation where experimentally determined constant nominal stress curves were determined for five alloys.

In general, considerable improvement in the correlation of the data was obtained with this parameter. The generalized correlation method also leads to a suggested explicit relation among stress, temperature, and rupture time. The experimental results were found to agree with this relationship over wide ranges of the variables for all five materials.

Many parts of a jet engine are subjected to high stress concentrations. An investigation of the influence of these stress concentrations on the strength of materials, when subjected to creep loading, was expanded to include additional alloys that might be used in jet engines. Sharply notched and smooth bar stress-rupture tests were carried out on a number of ferritic low-alloy steels, ferritic stainless steels, and austenitic alloys.[9]

The general time-temperature dependence of the notch effect in stress-rupture tests has been confirmed for a wide variety of materials. An analysis of the ductility data revealed that the smooth bar reduction of area at fracture yields no definite information regarding the notch rupture sensitivity of a given alloy. The notch ductilities were found to conform with the previous hypothesis that the weakening effect of a sharp notch is associated with a retained stress concentration.

Consideration of published data for total creep on certain of the alloys indicated that in some cases design for a certain total deformation would be limited by the notch strength.

Notch and smooth bar stress-rupture tests were also carried out on the chromium-molybdenum-vanadium steel 17–22A (S) over a wide range of temperatures from 600° to 1,350° F.[10] This systematic series of tests was designed to yield precise information on the time-temperature dependence of the notch effect in this low-alloy steel. The specimens possessed 50 percent 60° sharp V-notches and were tested for times up to 1,000 hours.

It was found that the trends of both the notch rupture-strength ratio and the notch ductility, when plotted against testing temperature with time as a parameter, conform with the previously advanced hypothesis that a precipitation reaction is associated with the notch sensitivity. A further analysis of these data yields an activation energy for the process which is close to that obtained for diffusion of carbon in alpha iron.

The same steel was used to investigate the influence of notch depth at 1,100° F. The results indicate a strong similarity between the behavior of a notch ductile alloy in stress-rupture tests and in room-temperature tensile tests. For the notch brittle conditions, it was found that the depth at which the onset of notch sensitivity occurred shifted to lower values with an increase in the testing time. In addition, for rupture times exceeding a certain value, it appeared that any sharp notch, however shallow, results in a weakening effect.

Available information on the behavior of brittle and ductile materials under conditions of thermal stress and thermal shock was reviewed. A simple formula relating physical properties to thermal shock resistance of brittle materials was derived and used to determine the relative significance of two indices currently used to rate materials (Technical Note 2933). The importance of simulating operating conditions in thermal-shock testing was deduced from the formula and experimentally illustrated. It was found that for ductile materials, thermal shock resistance depends upon the complex interrelationship among several metallurgical variables which seriously affect strength and ductility.

The influence of temperature gradients on the deformation and burst speeds of rotating disks was investigated experimentally and by means of plastic flow calculations (Technical Note 2803). Short-time spin

[9] See Brown, Jones and Newman paper listed on p. 51.

[10] See Newman, Jones and Brown paper listed on p. 52.

tests on parallel-sided, 10-inch-diameter disks were conducted under conditions that subjected the disks to a range of temperatures. Measured plastic strains and experimental burst speeds were compared with the strains and burst speeds calculated from the short-time tensile properties of the disk material. The agreement between the theoretical and experimental results was good over the wide range of temperature conditions investigated. Thermal gradients produced little reduction in burst speed of the high-ductility disks; however, these gradients had a strong influence on the behavior of the disk during the early stages of plastic flow. The loss in tensile properties of the material caused by the temperature of the material had a greater effect in reducing the burst speed than did the stresses set up by the thermal gradient.

Physics of Solids

Quantitative studies of the influence of the surface composition on the creep of zinc single crystals under constant loads gave results which are in accord with the theory that a continuous layer of oxide strengthens the crystal only mechanically at low loads. However, at high loads, the oxide layer must crack since creep proceeds at a rate characteristic of the pure metal rather than the oxide layer. It was further observed that an increase in creep rate occurred when the pure metal surface was treated with dilute mineral acids, an effect which had not hitherto been observed, and which is not attributable to the strengthening effect of the oxide layer. An empirical equation of a new form was developed to describe the creep curves of unoxidized crystals in air which do not follow previously existing equations.[11]

As the first step in a study of the thermodynamic activities of copper alloys, the vapor pressure of pure copper was measured. By using the Knudsen effusion technique in its unmodified form, it has been possible to obtain values between 1242° and 1563° K. with relatively high precision.[12]

Work on order-disorder phenomena has been continued. The specific heat and the energy of transformation were measured in the range from 50° to 200° C. for the alloy Mg_3Cd using an adiabatic calorimeter. Two transformations of the second order were detected: the one took place at 153.3° C., indicating a curie point for the alloy in equilibrium; the second occurred somewhat below 100° C., being of a rate-process type. The total heat involved in these transformations was obtained.[13]

In addition, a theoretical investigation resulted in the derivation of an expression for the free energy of a binary, cubic alloy undergoing the order-disorder transition by direct evaluation of the configurational partition function. An equation based on this expression and valid at high temperatures was developed which gives the dependence of the specific heat for such an alloy on temperature.[14]

Previous experiments dealing with color centers in alkali halide crystals had shown that a metastable state could be established in sodium-chloride (NaCl) crystals by electrolysis, the state being characterized by a high sensitivity for the formation of nonpermanent color centers upon irradiation with X-rays. Crystals in this state were consequently said to contain color-center precursors. To arrive at a more thorough understanding of the processes involved in setting up color-center precursors, measurements were made of the apparent free sodium content of NaCl crystals containing color centers and color-center precursors. The ratio of the number of free sodium atoms to vacancy pairs was found to be about 1 for crystals which had been subjected to electrolysis, and about 0.1 for crystals irradiated with X-rays independent of whether these crystals had been first subjected to electrolysis.[15]

In a further attempt to understand the effects of irradiating materials with X-rays (radiation damage), a study was made of the thermoluminescence of fluorite colored by X-rays. Fifteen emission bands were observed when the crystals were annealed. Continuous annealing curves which were obtained for the strongest emission bands indicated that the bands resulted from two distinct types of imperfections in the crystal resulting from X-ray bombardment.[16]

ROCKET ENGINES

Combustion instability has been encountered during various phases of the development of liquid-propellant rocket engines. This combustion instability is characterized by sustained oscillations in combustion-chamber pressure over a wide frequency range. This problem has been the subject of a number of investigations. A recent study of the spray formed by impinging jets of water indicated that upon impingement, a ruffled sheet of liquid was formed which disintegrated intermittently to form groups of drops which appear as waves propagating from the point of impingement. The effect of various injector parameters on the frequency of wave formation and on the spray pattern was investigated because of its possible relationship to combustion instability.

One form of combustion instability, termed chugging, is a cyclical low-frequency type that exhibits

[11] See Coffin and Weiman paper listed on p. 51.
[12] See Hersh paper listed on p. 51.
[13] See Weiber, Webeler, and Trumbore paper listed on p. 53.
[14] See Schwed and Groetzinger paper listed on p. 52.
[15] See Hacskaylo and Otterson paper listed on p. 51.
[16] See Hill and Aron paper listed on p. 51.

chamber pressure and nozzle flow or thrust fluctuation in the frequency range of 10 to 200 cycles per second. This type of instability may reduce specific impulse and is believed to be accompanied by changes in combustion efficiency. Results of experimental measurements of low-frequency combustion instability of a 300-pound-thrust acid-heptane rocket engine were compared with the trend predicted by an analysis of combustion instability in a rocket engine with a pressurized-gas propellant pumping system. (Technical Note 2936.)

For the past several years, considerable interest has been shown in film cooling as a promising method of cooling rocket engines. Film cooling is accomplished by establishing a film or layer of liquid between the hot gases and the confining wall, the film of liquid thus shielding the wall from the hot-gas stream. The overall flow system therefore consists of the simultaneous flow of a gas and a liquid with the liquid flowing as an annulus or film along the duct wall, and the gas flows at high velocities through the central core. This flow system is termed annular liquid flow with cocurrent gas flow and is one of several types of two-phase, two-component flow systems. An understanding of the annular liquid-flow system is therefore desirable for its application to film cooling. Visual observations and flow analysis were made of annular liquid flow with cocurrent air flow in horizontal tubes. The effect of liquid properties and air-stream conditions on the characteristics of the liquid flow were observed. The results were presented in the form of shadowgraph pictures of the liquid flow. Analysis of the flow system related the characteristics of the liquid flow to the flow conditions.[17]

An experimental investigation of internal-liquid-film cooling was conducted in 2- and 4-inch diameter straight metal tubes with air flows at 600° to 2,000° F. and Reynolds numbers from 2.2 to 14 x 10^5. The coolant was water at flows of 0.8 to 12 percent of the air flow. Visual observation of liquid-film flows were made in transparent tubes with air flows at 80° and 800° F. and diameter Reynolds numbers from 4.1 to 29 x 10^5. Flows of water, water-detergent solutions, and aqueous ethylene glycol solutions were investigated (Report 1087).

Nitric acid is an important oxidant in rocket propulsion. This use requires data on the physical properties of the concentrated acid. Consequently, a literature survey and a supplemental experimental study were made to obtain information on the following physical properties: thermal conductivity, dynamic viscosity, specific heat, density, and vapor pressures (Technical Note 2970).

[17] See Abramson paper listed on p. 51.

AIRCRAFT CONSTRUCTION

The need for increased research in the field of aircraft construction continues. More and more it is being appreciated that significant advances in aeronautics are going to be dependent on our knowledge of the behavior of aircraft structures under the ever expanding environment of flight. The so-called thermal barrier resulting from aerodynamic heating at high speeds looms as an important obstacle to the designer of new airplanes and missiles. The inter-relation of this problem with problems in aeroelasticity and flutter add serious complications to the design of new structures and the selection of new materials. Fatigue of aircraft structures also continues to be of major importance not only to transport type aircraft but also to aircraft subjected to lower numbers of extremely high loads and to aircraft where there is a cyclic load pattern as in a heliocopter rotor mechanism.

In order to promote the early use of research results in the design and development of airplanes and missiles, the practice of holding technical conferences with representatives of the military services and the aircraft industry was continued during the past year. A technical conference on structures, loads, and flutter problems was held at the Langley Laboratory in March 1953.

As in the past, a portion of NACA's research in this field was performed under contract at universities and other nonprofit scientific institutions. A description of the Committee's recent unclassified research on aircraft construction is given on the following pages and is divided into four sections: Aircraft structures, aircraft loads, vibration and flutter, and aircraft structural materials.

AIRCRAFT STRUCTURES

Static Properties

In order to support the severe loads encountered in supersonic flight and to obtain adequate torsional stiffness, wing structures of thick plate construction are being used. Recent structures research by the NACA has placed emphasis on methods of analysis for such thick-plate construction.

If the form of the thick-plate structure is the same as that of a familiar thin-sheet structure, some extension of previous methods of analysis may be adequate to take into account the use of thicker material. For example, the experimental investigation reported in Technical Note 2930 showed that the methods of beam-web strength analysis presented in the last annual report (Technical Note 2661) are applicable to beams with thick webs, provided that previously neglected portal-frame action associated with the thick webs is taken into account.

More frequently, thick-plate construction is most economically incorporated in a new constructional form. For wings, the use of thick skins permits a reduction in the number of stiffening elements required to prevent skin buckling. Thus, with thick skins, pure monocoque, multiweb wings, and multiweb wings with various combinations of stiffeners between webs and stiffeners supported by posts become more suitable than the old thin skin-stiffener construction. The new forms of wing construction have been studied in a series of investigations, both theoretically and experimentally.

In Technical Note 2875 an analysis was made of the bending strength of a pure monocoque wing and it was shown that failure of such a wing will occur by a flattening action not encountered in previous types of wing construction.

The use of a number of shear webs to support wing skins has been investigated both experimentally and theoretically. The factors which influence the strength of multiweb construction have been determined from the experimental studies. In Technical Note 2987 these factors are analytically evaluated and charts are presented for the evaluation of the strength of beams for a wide range of types of multiweb construction.

The use of stiffeners between shear webs for multiweb wings is, in some cases, economical from a production cost and from a structural weight standpoint. This form of construction can be analyzed by the methods given in the previously cited Technical Note 2987, provided the properties of the stiffeners are correctly evaluated. The properties of stiffeners attached to one side of a sheet or plate are analyzed in Technical Note 2873 and this analysis may be used to evaluate the properties of stiffeners between shear webs.

The use of stiffeners between shear webs with the stiffeners supported at intervals by posts provides a wing internal structure of greater accessibility than can be achieved with solid shear webs alone. An analysis comprising a series of computations performed on the National Bureau of Standards SEAC digital computer, together with test results, delineates the regions in which such post-stiffener construction can be successfully substituted for multiweb construction.

The large root chord of delta-plan-form wings reduces the intensity of loading on both tension and compression covers and makes a thinner skin more adequate for delta plan forms than for those with smaller root chords. Hence, thin skin-stiffener construction may still be suitable for much of the structure in delta wings. In previous years the NACA has provided extensive information on basic column behavior as well as on the compressive strength of skin-stiffener panels tested as columns. Further information on these subjects is provided in Technical Note 2792 and Technical Note 2872. The latter paper shows graphically the effect of variations in stress-strain properties, column proportions, and initial curvature on column strength. The former confirms results previously obtained in column tests that hat-section stiffeners are not structurally superior to Z-section stiffeners. These results had been questioned on the basis that column tests are not sufficiently representative of actual conditions for which the skin-stiffener panel is part of a box beam. Box beam tests reported in Technical Note 2792, however, gave results similar to those previously found for column tests.

In recent years a considerable amount of progress has been made in the development of applications of electric-circuit analogies to problems in structural analysis. In order that structural engineers may better understand the process of designing such electric circuits, California Institute of Technology has described in Technical Note 2785 the analogy between electrical and mechanical systems to calculate the stresses and deflections of beams. This method of analysis has been applied to thin multicell wings with rather thick skin and no stringers. The analysis which is presented in Technical Note 2786 shows that such a wing deflects in the manner of a plate rather than as a beam and that the internal stress distributions may be considerably different from those given by beam theory.

The accurate calculation of the maximum strength of aircraft structures usually requires stress analysis in the plastic range. In Technical Note 2886, a procedure is given for the analysis of statically indeterminate trusses having members stressed beyond the elastic limit. The method, based on the principle of minimum complementary energy, involves setting up simultaneous nonlinear equations that can be readily solved by iteration.

When a thin-curved beam of small curvature is subjected to lateral loads acting toward the center of curvature, the axial thrust induced by the bending of the arch may cause the arch to buckle so that the curvature becomes suddenly reversed. This problem has been investigated by California Institute of Technology and a general solution is presented in Technical Note 2840.

The ability to calculate accurately the distortion of aircraft wings and tails is essential for aeroelastic analysis. The distortion of delta wings having carry-through bays smaller in chord than the wing root chord are dealt with in Technical Note 2927. Experimental deflection patterns are given for solid metal specimens of uniform and tapered thickness and fair correlation is achieved with a theoretical analysis based on plate bending theory.

Dynamic Properties

For very sudden loadings, such as those that may occur in hard landings, the usual methods of stress analysis of wings and fuselages based on elementary-beam theory are not adequate. The beam equations of Timoshenko, taking into account shear deformations and rotary inertia, are more accurate and lend themselves to a step-by-step analysis of the stresses as they propagate through the beam. In Technical Note 2874, a basic theoretical study of traveling waves in beams is reported; the mathematical implications of Timoshenko's equations are discussed in detail, and the solutions to several problems are obtained by various methods.

Fatigue Properties

The fatigue problem in aircraft structures has been sharply accentuated as a result of a number of major accidents, in this country and abroad, that can be attributed to fatigue. Although many fatigue tests of small laboratory specimens have been made to supply basic knowledge and engineering information about fatigue, such tests do not reproduce the complex conditions that exist in a full-scale built-up structure. Therefore, full-scale C-46 "Commando" airplane wings were subjected to fatigue tests at a level of 1g±0.625g or about 1g±14 percent of the design ultimate load. The results of these tests are presented in Technical Note 2920. Information was obtained on effective stress concentration factors, the spread in lifetime for various locations of fatigue failures, and on the rate of growth of fatigue cracks. It was also noted that no change occurred in the natural frequency or damping characteristics of the wings prior to development of a fatigue crack.

Thermal Properties

Nonuniform heating induces thermal stresses in the structure of an aircraft. If the stresses are sufficiently large, the induced stresses may cause buckling of the skin of the aircraft. In Technical Note 2769 an experimental and theoretical study was made to assess the suitability of wire strain gages for measuring the thermal strains induced under moderate nonuniform temperatures, up to 300° F., and to develop simple methods of thermal stress analysis. It was found that, with adequate calibration, the strains measured by wire gages agreed within 5 percent with those predicted by theory. It was also found that moderate temperature gradients induced in a plate (less than a change of 150° F. in 12 inches) were sufficient to buckle the plate and produce large bending deflections. In Technical Note 2771 an approximate method, based on large-deflection plate theory, was developed to predict the depth of the buckles.

Two studies of a preliminary nature have been completed to determine ways by which available room-temperature data on structural strength may be used to determine the strength at elevated temperatures. A survey has been made of the problem of predicting structural strength at elevated temperatures. In Technical Note 2963 a study is made of the effect of variation in rivet strength on the strength of skin-stiffener panels to provide a basis for the determination of the effect of riveting on the strength of structures at elevated temperatures.

Because high temperatures can develop in the structures of supersonic aircraft, creep may have to be considered in the structural design of such aircraft, especially those intended for sustained or repeated flights. The creep problem in supersonic aircraft has an important aspect not generally encountered in other high-temperature equipment, inasmuch as a large part of the aircraft structure consists of plate compression elements which are relatively thin and which unavoidably have slight initial crookedness. Creep in such elements will tend to magnify the crookedness continuously and eventually lead to collapse. As an initial step in the study of creep strength of columns an analysis was made of a slightly bent H-section column under constant load. An extension of this work to include the effect of the actual distribution of material over a rectangular cross section is presented in Technical Note 2956. This analysis revealed theoretical parameters in terms of which test data on column creep life should be plotted in order to permit the maximum generalization of the data.

AIRCRAFT LOADS

Research Techniques

A general method has been developed for calibrating installations of strain gages on aircraft structures to permit the measurement in flight of the shear or lift, the bending moment, and the torque or pitching moment on the principal lifting or control surfaces. The results of this investigation are presented in Technical Note 2993. Although the stress in a structural member may not be a simple function of the shear, bending moment, and torque, a straightforward procedure is given for numerically combining the outputs of several strain-gage bridges in such a way that the loads may be obtained. In addition to the basic procedures, extensions of the method are described which, by electrical combination of the strain-gage bridges, permit compromises between strain-gage installation time, availability of recording instruments, and data reduction time. The basic principles of strain-gage calibration procedures are illustrated by reference to the data for two aircraft structures of typical construction, one, a straight, and the other, a swept horizontal stabilizer.

Steady Flight Loads

A considerable amount of load data useful for the structural and aerodynamic design of aircraft have been obtained from pressure-distribution tests of a 45° swept wing of aspect ratio 8. Wing loads produced by trailing-edge flaps of various spans at various spanwise positions are reported in Technical Note 2983. The experimental incremental lift, bending moments, pitching moments, and centers of pressure are compared with calculated values. This comparison indicates that there is a need for improved methods for calculating these parameters.

It has been shown that a satisfactory mathematical model for a wing-fuselage combination can be obtained with a simple vortex image system. By using this scheme, a method of calculating the lift on the fuselage in the presence of the wing has been derived. This mathematical model can also be used for calculating the downwash behind the wing and for calculating the spanwise lift on the wing in the presence of the fuselage.

A simpified analysis has been made of the factors affecting the loss in lift and the shift in aerodynamic center of a swept wing due to its distortion under aerodynamic load. The manner in which these aeroelastic effects influence the loads and longitudinal stability of a complete airplane is considered. Results of this analysis, presented in Technical Note 2901, show that the most important geometric parameters of a wing with regard to their influence on aeroelastic effects are aspect ratio, sweep angle, and thickness ratio. With the thickness ratios being contemplated today, aeroelastic considerations would appear to restrict the wing aspect ratios to low values for large sweep angles and, conversely, restrict sweep angles to low values for high aspect ratios. Although the effects of wing torsion, in general, tend to alleviate the effects of wing bending, the magnitudes of the torsional distortion are usually small compared with those due to bending except for wings with low sweep or aspect ratio. Some alleviation of aeroelastic effects occurs in maneuvers because of the inertia of the wing. In addition, the effect of wing-aerodynamic-center shift on the longitudinal stability of an airplane may be compensated for by the associated loss in wing lift provided the percentage reduction in wing-lift-curve slope is greater than that for the tail.

Maneuver Loads

During the past year attention has been given to the problem of devising a simple and rational method for computing the design maneuver load on the horizontal tail. A damped sine wave elevator motion simulating the Air Force pull-up push-down maneuver is suggested in Technical Note 2877 as an alternate procedure for computing the design load on the horizontal tail. The damped sine-wave motion is not only more representative of that actually applied in flight but it permits a simple short solution for the maneuvering tail load using operational methods.

An investigation to determine the effect of horizontal-tail span and vertical position on the aerodynamic characteristics of an unswept tail-stub fuselage assembly in sideslip is reported in Technical Note 2907. The results indicate that the induced load carried by the horizontal tail and the net load on the vertical tail were greatly influenced by the horizontal-tail span and vertical position, the greatest effects occurring when the horizontal tail was placed at either the root or tip of the vertical tail. It was found that loads on the individual tail surfaces, as well as on the entire assembly, could be calculated fairly well by use of the finite-step horseshoe-vortex method, wherein the tail surfaces are represented by a finite number of horseshoe vortices.

Gust Loads

Methods used in the description of atmospheric turbulence and the calculation of gust loads have for simplicity been restricted to the case of a single discrete gust. The limitations of this approach have, in recent years, encouraged the development of more generally applicable techniques. In Technical Note 2853 the techniques of generalized harmonic analyses have been used to extend the scope of the analyses beyond the discrete-gust case to the more realistic case of continuous rough air. The concept of a power spectrum has been used to describe continuous rough air and the general relation for linear systems between the power spectrums of a random disturbance and an output response used to relate the spectrum of load to the spectrum of atmospheric gust velocity. The results obtained show that the spectrum of loads provides a simple measure of the load intensity in terms of the root-mean-square of the loads. Experimental evidence indicates that in some cases the distribution of loads in rough air is approximately normal and is thus completely described by the standard deviation. The results obtained in an application of this approach in a series of calculations indicate that the airplane short-period damping characteristics may have an important effect on the loads in continuous rough air.

In order to provide for uniformity of gust-load calculations, a revised gust-load formula with a new gust factor has been derived to replace the previous gust-load formula and alleviation factor widely used in gust studies. The revised formula utilizes the same principles and retains the same simple form of the original formula but provides a more appropriate and acceptable basis for gust-load calculations. The gust factor is calculated on the basis of a one-minus-cosine gust shape and is presented in Technical Note 2964 as a function of a mass-ratio parameter in contrast to the ramp gust shape and wing loading formerly used for the alleviation factor.

One of the problems that concerns the aeronautical engineer in the formulation of his design relative to critical airplane loading is the effect of Mach number on the maximum value of the load induced on an airplane by its sudden entry into a gust of given structure. This effect has been estimated in Technical Note 2925, on the basis of theoretical calculations, for rectangular wings having an aspect ratio greater than 2 and flying at any Mach number between 0 and 2. The airplane wing is considered to be rigid and to undergo a negligible angle of pitch in the time required for the maximum gust load to develop. In general it was shown that decreasing the wing aspect ratio and the wing-to-air density ratio decreased the maximum gust load, and the reductions were most pronounced at high subsonic Mach numbers.

Normal acceleration and airspeed data obtained for one type of twin-engine transport airplane in commercial operation over a northern transcontinental route have been analyzed to determine the gust and gust-load experiences of the airplane. The results are reported in Technical Note 2833. The data covered a period of about 1½ years and consisted of 388 records for about 39,000 flight hours. These data are almost a complete history of this type of airplane for the period covered inasmuch as the 24 airplanes instrumented constituted nearly all the airplanes of this type that were built. The acceleration increments experienced equaled or exceeded the limit-gust-load factor, on the average, twice (once positive and once negative) in about 7.5×10^6 flight miles, and an effective gust velocity of 30 feet per second was equaled or exceeded twice in about 1×10^6 flight miles.

The results of an analysis of 48,187 hours of normal-acceleration and airspeed data, obtained on a 4-engine type of transport airplane operating at altitudes up to 20,000 feet in commercial operation on an eastern United States route from November 1947 to February 1950 are reported in Technical Note 2965. The analysis indicates that the gusts encountered were less severe than those previously encountered in operations below 10,000 feet although about as severe in terms of percent of limit load factor. The analysis also indicates that high airspeeds were attained more frequently. The gust and gust-load experience during the summer (April through September) was found to be approximately 20 percent more severe than during the winter (October through March).

An analytical evaluation of the gust-response characteristics of three twin-engine transports and a 4-engine bomber with wing bending flexibility included, together with a limited correlation of some of the calculated results with flight data is presented in Technical Notes 2763 and 2897. The effect of gust-gradient distance, gust shape, spanwise mass distribution, forward velocity, altitude, compressibility corrections, and aspect-ratio corrections on dynamics were investigated. The results indicate that three of the airplanes have rather appreciable elastic-body dynamic-overshoot effects, but one does not.

The analyses of results obtained during flight studies of transient wing response on a 4-engine bomber airplane are reported in Technical Notes 2780 and 2951. Acceleration and strain measurements at a number of spanwise stations were made during flights through clear-air turbulence for two speeds and two weight conditions. The amplification of strain due to flexibility effects was determined by comparing the strains developed for a unit normal acceleration when the airplane encounters a gust to the strains developed for a unit normal acceleration in a pull-up. The results indicated that the strains at a station near the wing root were on the average 31 percent greater for the gust case than for the corresponding pull-up. The amplification was also found to vary with spanwise location, diminishing slightly at successive outboard stations except at the most outboard station where it increased. This is in contrast to previous results for a two-engine transport where an amplification of 20 percent was indicated for each of the measuring stations.

A gust-tunnel investigation to determine the effects of center-of-gravity position on the gust loads on a delta-wing model with the leading edge swept back 60° and for a range of center-of-gravity positions from 4 percent ahead of to 11 percent behind the leading edge of the mean geometric chord indicated that a 1 percent rearward movement of the center-of-gravity position increased the acceleration increment in the sharp-edge gust by 0.5 percent. In a gust with a gradient distance of 6.5 chords, the acceleration increment was increased by approximately 2 percent for the same movement of the center of gravity. Comparison of these results with those for a conventional airplane model indicates that the change in load for both configurations would be nearly the same in a sharp-edge gust, but in a gust with a gradient distance of 6.5 chords, the change in load for a given change in center-of-gravity position would be approximately twice as great for the delta-wing model as for the conventional airplane model.

Landing Loads

Static force-deflection characteristics of six aircraft tires were determined for the following conditions: Vertical loading, combined vertical and side loading, combined vertical and torsional loading, and, for one tire at several inflation pressures, combined vertical and fore-and-aft loading. The results of this investigation are presented in Technical Note 2926. The lateral spring constants for all the tire specimens tested decreased with increasing vertical tire deflection; whereas, the torsional and fore-and-aft spring constants increased with increasing vertical deflection. The lateral and fore-and-aft shifts of the center of pressure of the vertical reaction were found to average 75 percent and 25 percent, respectively, of the side and fore-and-aft tire deflections.

Measurements have been obtained with a specially built motion-picture camera of landings of transport airplanes during routine operations at the Washington National Airport in clear-air daylight conditions. From these measurements, sinking speeds, roll attitude angles, and rolling velocities have been evaluated. The equipment and technique employed for the measurements have been found to be accurate and practical, at least for daytime operations. Continued operation of the project, in which horizontal velocities will also be determined, is expected to yield information on the influences of various factors such as airplane characteristics and weather conditions (turbulence, lowered ceilings, reduced visibility, and so forth). An airborne vertical landing-speed recorder has also been developed and tested in controlled drop tests with forward velocity as well as in flight on a small trainer-type airplane. A description of the operation of the instrument together with collected data is presented in Technical Note 2906. Evaluation of the data shows that the instrument is both accurate and practical for obtaining vertical velocities at the instant of wheel contact.

The general equations governing the fixed-trim water landing of a straight-keeled seaplane of arbitrary constant cross section are presented in Technical Note 2814 in such a form that the landing motions and loads are expressed in terms of the steady planing characteristics of the seaplane. Solutions for a rectangular flat plate are compared with experimental impact data and are shown to be in good agreement. Experimental impact load data for a V-step flat-bottom model having a high beam loading presented in Technical Note 2932 show results similar to those for transverse steps, and comparisons of time histories show good agreement between experimental results and results computed by the method of Technical Note 2814. The effect of partial wing lift upon the loads and motions of wide prismatic V-bottom seaplanes landing with the resultant velocity normal to the keel is treated theoretically in Technical Note 2815. The increase in vertical hydrodynamic load factor is shown to be about 133 percent of the decrease in air load. Additional development in hydrodynamic impact theory is presented in Technical Note 2817 where calculated side-force, rolling moment, yawing moment, and pressure distribution for yawed landings and planing of seaplanes are compared with experimental data for a prismatic wedge having a deadrise of 22.5° and are shown to be in reasonable agreement.

Water-pressure distributions on a prismatic float having an angle of dead rise of 22½° are given in Technical Note 2816 along with velocity, draft, and acceleration data. These data are for beam-loading coefficients of 0.48 and 0.97, fixed trims from 0.2° to 30.3°, and flight-path angles from 4.6° to 25.9°.

An approximate method for computing water loads and pressure distributions of lightly loaded elliptical cylinders during oblique water impacts is presented in Technical Note 2889. The method, of special interest for the case of water landings of helicopters, makes use of theory developed and checked for landing impacts of V-bottom seaplanes. Comparison of results computed by this method with limited experimental data obtained during drops of a circular cylinder at 0° trim and 90° flight-path angle shows rough agreement.

VIBRATION AND FLUTTER

Dynamic Model Technique

There are so many unknown factors, both structural and aerodynamic, involved in the flutter analysis of an unusual airplane configuration flown at sonic and supersonic speeds that recourse is being made to the testing of models having scaled down dynamic properties. Many of these models are tested in flight using the rocket model technique. The testing of such models in a wind tunnel is under consideration and effort is being directed toward the development of a method of supporting the model in the tunnel which will allow the model the degrees of freedom which are required to simulate the flutter conditions of the full scale airplane.

Fuel Motion in Wing Tip Tanks

When an airplane wing is vibrated or shaken due to flutter, buffeting, or rough air the sloshing motion of the fuel serves to damp the wing motion. In Technical Note 2789 are reported the results of an exploratory investigation of the dynamic effects of fluid sloshing in tip tanks using two simplified model beam-tank systems. It was concluded that the damping effect of the fluid motion and the effective mass of the fluid were unaffected by changes in viscosity of the fluid but were strongly affected by changes in density of the fluid and the amount of fluid in the tank.

AIRCRAFT STRUCTURAL MATERIALS

Fatigue

Fatigue failure due to variable or constant cyclic loading is an important phase in the design of aircraft structures and structural elements. Efficient use of available materials was once dependent only upon the knowledge of such properties of the materials as strength, ductility, stiffness, etc. Knowledge of the fatigue properties of the various materials has been recognized for some time as an addition to these structural properties. The NACA, therefore, instituted a long-range program to determine the fatigue properties of currently used aluminum-alloy sheet materials. Axial load fatigue data were obtained on 24S–T3 and 75S–T6 aluminum alloy sheet at both the Langley Laboratory and Battelle Memorial Institute. A third set of data was obtained from tests on cylindrical specimens by the Aluminum Company of America. The data from the three investigations are presented and compared in Technical Note 2928.

The direct application of fatigue data obtained in laboratory tests of small specimens to the design of large parts can lead to large unconservative errors for several reasons. One of these reasons is the fact that the fatigue stress concentration factors, for geometrically similar parts, tend to increase as the size of the part increases. An engineering rule for predicting the effect of the size of parts on the stress concentration factors has been developed. A relation originally developed by Neuber in Germany and involving a new material constant is used to convert the theoretical stress concentration factor, which does not depend on absolute size, into the actual fatigue factor. A large number of fatigue tests of steels tested under completely reversed load have been correlated reasonably well by the method. This work is presented in Technical Note 2805.

The simplest type of fatigue test is usually made for constant levels of maximum and minimum stress. Many practical cyclic loading conditions, such as the one found in aircraft wings, occur at varying amplitudes of cycles of stress. The prediction of the life expectancy of such parts when subjected to irregularly varying stresses from constant-level data requires the knowledge of the cumulative damaging effect of the successive application of such stress cycles. An experimental investigation was conducted in which 24S–T4 aluminum-alloy rotating-beam specimens were subjected to cycles of stresses of constant amplitude and of two distributions of continuously varying amplitudes. The results and a preliminary analysis, based on an engineering method of predicting cumulative effects, are presented in Technical Note 2798. The results of the analysis were found to be influenced by the distribution of continuously varying amplitudes of cyclic stress.

The effects of cyclic loading on the mechanical behavior of 24S–T4 and 75S–T6 aluminum alloys and SAE 4130 steel were studied at the Massachusetts Institute of Technology. Constant level stress tests were made on specimens subjected to a number of cycles above and below the endurance limits. Special slow-bend tests were then performed at constant deflection rates and temperatures to determine the effects of prior cycles of fatigue stresses on the transition temperature to brittle fracture of SAE 4130, and on the energy absorption capacity of the aluminum alloys. These tests showed an increase in the transition temperature for the steel when fatigued above the endurance limit, and a decrease in energy absorption for the aluminum alloys as the number of fatigue cycles increased. In tests conducted at low temperatures (−320° F.) on V-notched specimens, 75S–T6 showed considerably less energy absorption than 24S–T4. These results are presented in Technical Note 2812.

Creep

The properties and behavior of materials subjected to long-term loading at elevated temperatures must be known before efficient design of many structural elements can be accomplished. Creep of materials is one of the basic phenomena associated with elevated temperatures. The program instituted at the Battelle Memorial Institute to study the fundamentals of creep of materials is continuing. That portion of the program reported in Technical Note 2945 covers the creep of single crystals of aluminum from room temperature to 400° F. during constant load creep tests and increasing load tensile tests. Observation of the strain markings on the specimens indicates that slip plays an important role in deformation during constant load creep tests and also during increasing load tensile tests.

The frequency distribution of the angular orientation of slip lines within separate grains on the surface of a plastically deformed polycrystal provides a basis for assessing the accuracy of assumptions regarding the detailed mechanism of plastic deformation. In Technical Note 2777 this frequency distribution has been calculated theoretically for a polycrystal composed of aluminum crystals, each of which has twelve possible modes of slip. The results are compared with experiment and also with those previously reported in Technical Note 2577 (reported in the last annual report) for a polycrystal composed of crystals which have but a single mode of slip. The comparisons between the two theories show that the differences are small at low stress levels but become large as the stress level is increased; the comparison with experiment is considerably better for the twelve-mode theory than for the single-mode theory.

In an investigation carried out at the Pennsylvania State College and reported in Technical Note 2737 an attempt was made to determine the validity of several theories of plasticity and the correctness of the various assumptions made in these theories. Plastic stress-strain relations for biaxial tension-compression stresses were determined for 14S–T4 aluminum alloy. Combined tension and compression principal stresses were produced by subjecting a thin-walled tube to combined axial tension and torsion.

Plastics

Transparent cabin enclosures used in the modern pressurized military or commercial airplanes are subject to failure by crazing or impact. The National Bureau of Standards is continuing a project to determine means of improving craze resistance of plastics and has biaxially stretched polymethyl methacrylate to 100 percent and 150 percent. Ultimate tensile strengths were increased slightly. The threshold stress for stress-solvent crazing was approximately three-fourths of ultimate stress and close to the ultimate stress for the 100 percent and 150 percent biaxially stretched material, respectively.

OPERATING PROBLEMS

During the past year, aircraft have been flown at higher speeds, higher altitudes and with greater frequency than ever before. This ever increasing frequency of flight under these conditions has accentuated some of the operating problems that are pertinent to safety and to the successful attainment of all-weather flight; namely, aircraft fire, icing, meteorology, crash survival, and ditching. Another very important operating problem currently being investigated intensively is that of the noise generated by the high-powered engines being employed in these high performance aircraft. Although the NACA has established the basic principles of aircraft engine and propeller noise suppression for conventional aircraft of the recent past, the noise generated by the turbo-jet and turbo-prop engines now in use and coming into use is of substantially greater magnitude and requires new techniques for its suppression. The gravity of this situation led to the creation of a Special Subcommittee on Aircraft Noise in 1952. Under the guidance of this subcommittee, research in this field has been intensified. This subcommittee has been very active and, in view of the current broad research and development activity within the noise field, has maintained close liaison with other organizations. To accelerate progress in this field a series of informal conferences have been initiated to bring together the various workers both in this country and abroad to exchange information and assist in pinpointing the most urgent and desirable research to be undertaken.

Although the magnitude of the noise problem is well understood and a comprehensive program of research is vigorously being pursued, the problem is of such a difficult nature that early solutions are not to be expected.

Other NACA groups that have helped guide the research which has been carried out in the three NACA laboratories and under contract with nonprofit research organizations include, in addition to the parent Committee on Operating Problems, the Subcommittee on Icing Problems, the Subcommittee on Meteorological Problems, and the Subcommittee on Aircraft Fire Prevention.

The following is a résumé of the various unclassified research accomplishments in Operating Problems during the past year.

Airspeed Measurement at High Speeds and Altitudes

Detailed measurements of temperature and static pressure at altitudes approaching the tropopause were taken in flight to determine whether the atmospheric conditions necessary for accurate use of the temperature method of airspeed calibration were present. The results of the investigation (Technical Note 2807) indicated that the requirements for constancy of temperature over small intervals of time and horizontal distance and for a temperature lapse rate less than the NACA standard atmosphere were not met during the tests. The temperature method of airspeed calibration therefore was considered impractical at high subsonic speeds in the altitude range just below the tropopause.

Ditching

An experimental investigation has been conducted to study the effects of various rear fuselage shapes on aircraft ditching behavior. The results (Technical Note 2929) indicate that, at low landing speeds, a flattened rear-fuselage cross section is advantageous except where there is no longitudinal bottom curvature. At the higher landing speeds, it was noted that a rounded cross section tends to avoid undesirable skipping. In addition, the fuselage with the highest fineness ratio was more moderate in behavior.

Investigations of the ditching behavior of specific airplane configurations have been continued utilizing scale models. The tests were made in calm and rough water to determine the effects of various wing plan-forms and nacelle locations of new aircraft. Structural damage was simulated to show the behavior of the models following ditching impact.

Aircraft Accident Survival

Full-scale light-airplane crashes simulating stall-spin accidents were conducted to determine the decelerations to which occupants are exposed and the resulting harness forces encountered in this type of accident (Technical Note 2991). In crashes where the impact speeds varied from 42 to 60 miles per hour, crumpling of the forward structure prevented the maximum deceleration at the rear seat location from exceeding 26 to 33 *g*. Restraining forces in the seat-belt-shoulder-harness combination reached 5,800 pounds. It is concluded from this investigation that the rear seat occupant can survive crashes of the type studied at impact speeds up to 60 miles per hour if body movement is properly restrained.

During the conduct of the NACA Full-Scale Crash Fire Program, data were obtained concerning the factors which affect the survival of human beings in airplane accidents. The time intervals during which occupants could escape from burning aircraft were determined from the data provided by these studies. This was accomplished by using the time histories of cabin temperatures and toxic gas concentrations in conjunction with data that define the environmental conditions which can be tolerated by human beings. Survival times as limited by pain or skin burning ranged from 50 to 300 seconds. Other hazardous factors, such as flying detached airplane parts, explosions, and crushing of the airplane structure, were also studied.

AERONAUTICAL METEOROLOGY

Atmospheric Turbulence

A cooperative investigation among the NACA, Air Weather Service, the U. S. Weather Bureau, and the Brookhaven National Laboratory has been made to gather and compare turbulence measurements obtained by a suitably instrumented airplane flying in the vicinity of a tower with data from wind vanes on the tower. The results of the study indicate a good correlation between the vertical gusts measured by the airplane and the horizontal gusts evaluated from the vane motions, provided that the gusts selected during these simultaneous measurements have nearly the same wave length.

To gain more data on the frequency of occurrence and the degree of severity of high-altitude clear-air turbulence, a program for the collection of pilots' reports of the phenomenon encountered in normal civil and military operations was undertaken in 1949. During a 2-year period, several hundred encounters were reported and a summary of these data indicate that turbulence at high altitudes is a factor which should be considered in both the design and operation of aircraft.

Physics of the Icing Cloud

The meteorological parameters that define an icing cloud, so that accurate prediction of the severity of icing which may be experienced by various aircraft components in flight, include liquid water content and droplet size distribution. Although research toward the development of new principles to provide the basis for reliable instrumentation to measure these quantities accurately in flight has resulted in significant accomplishments in research instrumentation, the time delay between its use as a research tool and its development into an operational piece of equipment may consume several years, depending upon the required further development by industry and its acceptance by the aircraft operator. Development of aircraft instrumentation which will define the icing cloud along the aircraft flight path and which will feed this intelligence to the ice-protection system controls is at present a goal which may not be reached for many years, but which is certainly worthy of achievement if all-weather flight is to be attained with a minimum of operational and performance losses for optimum ice protection. Application of principles to measure the icing parameters have been previously reported in various NACA publications and include the cloud camera, the charge-droplet cloud analyzer, the rotating disk, the rotating multicylinder, the pressure-type icing-rate meter, the hot-rod, and the hot-wire icing severity meter.

Despite its disadvantages, perhaps the most widely used instrument is the rotating multicylinder, particularly in the field of flight testing of aircraft in icing conditions. Because of its continued use in this field, the NACA initiated a study of the phenomena of water-droplet impingement and related information on cylinders. The NACA water-droplet-trajectory analogue has been used to determine the impingement of water droplets on a cylinder in incompressible and compressible flow fields. The results of these studies (Technical Notes 2903 and 2904) have been used as a basis for evaluation of the sensitivity and limitations of the multicylinder method, especially as applied to droplet-size distribution. It has been shown that on the basis of droplet impingement alone, with other factors such as blow-off and Ludlam effect not considered, large errors in the measurement of drop size of the order of 70 percent can exist.

The NACA-Airline-Air Force icing data program which is utilizing about 100 installations of the NACA pressure-type icing rate meter to collect icing data on a world-wide basis has just completed its second icing season. One preliminary report of the analysis of data collected during the first year of the program has been published and preparations for the final data collection season for 1953–54 have been completed.

ICING PROBLEMS

The degree of ice protection required for any aircraft component is dependent upon many variables. The ideal solution is to provide enough protection to insure no compromise with safety and at the same time minimize the aircraft performance penalties associated with system weight, aerodynamic losses due to ice accretion, and system energy requirements. Recent NACA research has been directed toward study of ice protection design requirements for high performance aircraft of the high-speed turbojet category. The rather large increase in the operating speeds and altitudes of these jet aircraft over the more conventional type has dictated the need for more efficient and effective types of ice protection systems. The thin swept and unswept wings now being employed on these high-speed aircraft have also accented the requirement for data that will help the designer determine accurately, without expensive flight studies, the areas requiring protection. Other aircraft components requiring special studies include leading-edge slots, porous leading-edge wings, radomes, helicopter rotor blades, and air inlets and scoops.

The NACA droplet trajectory analogue has been used to determine the area, rate, and extent of impingement of water droplets on an NACA 65_1–208 airfoil for a range of altitude and icing conditions up to a speed equivalent to the flight critical Mach number of the airfoil. Variation of the impingement characteristics of this airfoil have been compared with those of an NACA 65_1–212 airfoil and the results are published in Technical Note 2952. A method for applying this type of impingement data to a sweptback airfoil has also been developed (Technical Note 2931). Impingement of water droplets on wedges and diamond shaped airfoils has been studied at supersonic speeds and the results are presented in Technical Note 2971 for a range of meteorological conditions.

Aircraft icing at high-flight speeds does not always present a problem since the component surface temperature increases with flight speed, due to aerodynamic heating, and when this temperature reaches 32° F. ice will no longer form. This phenomenon is known as the icing limit. The results of an analytical study of a general method for the rapid calculation of the icing limits of any given body in both subsonic and supersonic flow have been presented in Technical Note 2914, covering Mach numbers up to 1.8 and altitudes up to 45,000 feet. However, although the icing limit may be reached on the forward portion of an airfoil, the results of an analytical investigation of a diamond airfoil at transonic speeds (Technical Note 2861) show that the liquid water that runs back past the maximum thickness is subject to freezing in the reduced pressure area which indicates that areas behind this point may be susceptible to icing up to a Mach number of 1.4.

In the design of ice-protection systems, the solutions of equations of heat transfer and evaporation from wetted surfaces during an anti-icing process can be very laborious. These equations have been simplified and presented so as to permit solution by graphical means (Technical Note 2799). In connection with the design of ice protection systems, an analysis of the problems involved in providing icing protection for a turbojet transport aircraft has been made (Technical Note 2866). The optimum icing protection system for any particular aircraft cannot be generally specified since the choice of the optimum system is dependent upon the specific characteristics of airplane and engine, the flight plan, the probable icing conditions, and the performance requirements of the aircraft. However, this study presents all the ramifications associated with the heating requirements for various methods of protection (both cyclic and continuous) and the assessment of performance penalties associated with providing this protection from various energy sources.

For many years the degree of ice protection required for aircraft wings has been considered from the point of view that the wing should be clean after heat has been applied, whether it be involved in a cyclic or continuous type of system. The fact that most systems on operational aircraft do not afford clean wings under all meteorological conditions and that the resulting residual ice accumulated appears to affect the performance of the aircraft in varying degrees, a general study of the aerodynamic penalties associated with ice accretions has been initiated. As a first attempt to assess the performance penalties associated with ice accretions, an experimental investigation has been made in the Lewis 6- by 9-foot icing tunnel to show the effects on section drag characteristics of those accretions associated with conditions of cyclic de-icing, continuous anti-icing, and no protection on an 8-foot chord airfoil section for several angles of attack. Results of this investigation are encouraging and additional data, including lift and drag on other airfoil sections, should result in significant data from which a more realistic and general interpretation of the problem may be possible.

Other published information in the field of ice protection during the past year include (1) experimental studies of cyclic de-icing of a gas-heated airfoil with an evaluation of the effects of various parting-strips on system performance, (2) an investigation of the performance characteristics of three electrical de-icing boots designed for fighter-type jet aircraft, (3) an experimental investigation of an alternate carburetor air inlet configuration, (4) an experimental study of the dry-air heat transfer from a body of revolution, (5) an experimental study of radome heat requirements, and (6) an investigation to provide design data for the ice-protection of hollow-steel propeller blades utilizing electrical heaters.

AIRCRAFT FIRE PREVENTION

To aid in the reduction of the crash-fire hazards for reciprocating engine type aircraft, general distribution has been made of the very important results of the NACA Full-Scale Crash-Fire Program in the forms of a technical report and a technical motion picture in color and sound. This latter form of information distribution was necessitated because of the dynamics involved in the study of crash fires and the aircraft industry demand for a detailed account of these results for the instruction of their employees who are directly concerned with aircraft and equipment design for crash safety. Pilots are also being thoroughly briefed by this film and will therefore receive the background of the research and development leading to the equipment and piloting techniques that they will utilize in the event of a crash.

The NACA is continuing the study of the crash-fire hazard as it is related to the turbo-jet aircraft. Results to date indicate that many of the princples learned in the reciprocating engine type aircraft can be successfully applied to the turbo-jet type aircraft, even though the character of some of the ignition sources are significantly different.

In order to minimize the crash-fire hazard, the obvious advantage of jettisoning fuel prior to landing has been investigated to determine the fuel concentrations that may exist when the dumped fuel approaches the ground. The results of a study of the free-fall and evaporation of n-octane droplets in the atmosphere with reference to the jettisoning of gasoline at altitudes up to 11,000 feet over a droplet size range from 6 to 2,000 microns and for temperatures from −37° to +30° C. have been published. It was concluded that use of atomizing devices causing production of droplets *less* than *200 microns* in diameter would allow gasoline jettisoning without ground contamination at ground clearances in excess of 250 feet at temperatures above −37° C. Ground clearances of 1,000 feet should suffice even when the largest (0.2 cm.) droplets are present, that is, when no atomizing nozzles are used at temperatures up to +30° C.

AIRCRAFT NOISE

Propeller-Noise Charts for Transport Aircraft

The rotational and vortex noise levels, at 300 feet distance, for a number of propellers in static operation have been calculated for engine ratings of 1,000 to 10,000 horsepower. Charts and tables for the rapid estimation of the noise levels and spectrums for a range of tip Mach numbers from 0.40 to 1.00 (Technical Note 2968) are useful for design purposes. The results indicate that, if noise reductions are to be obtained or if present noise levels are to be maintained for higher power ratings, future propellers should operate at lower tip speeds than those now in use. In addition, single rather than dual-rotating propellers were found to generate the lowest over-all noise level for a given number of blades.

Muffler Research Program

An extensive theoretical and experimental muffler research program was undertaken to aid in establishing a rational basis for the design of mufflers for internal-combustion-type aircraft engines. A large number of muffler sizes and types were evaluated (Technical Notes 2893 and 2943) to determine the validity of equations developed from acoustical theories under certain simplifying assumptions. The results demonstrated that effective muffling was possible, but that the theoretically computed attenuation could not be realized.

RESEARCH PUBLICATIONS

REPORTS [1]

No.

1059. A Biharmonic Relaxation Method for Calculating Thermal Stress in Cooled Irregular Cylinders. By Arthur G. Holms.
1060. Detailed Computational Procedure for Design of Cascade Blades With Prescribed Velocity Distributions in Compressible Potential Flows. By George R. Costello, Robert L. Cummings, and John T. Sinnette, Jr.
1061. Effect of Initial Mixture Temperature on Flame Speed of Methane-Air, Propane-Air and Ethylene-Air Mixtures. By Gordon L. Dugger.
1062. Investigation of Wear and Friction Properties Under Sliding Conditions of Some Materials Suitable for Cages of Rolling-Contact Bearings. By Robert L. Johnson, Max A. Swikert, and Edmond E. Bisson.
1063. Airfoil Profiles for Minimum Pressure Drag at Supersonic Velocities—General Analysis With Application to Linearized Supersonic Flow. By Dean R. Chapman.
1064. Lubrication and Cooling Studies of Cylindrical-Roller Bearings at High Speeds. By E. Fred Macks and Zolton N. Nemeth.
1065. Correlation of Physical Properties With Molecular Structures for Some Dicyclic Hydrocarbons Having High Thermal-Energy Release Per Unit Volume—2-Alkylbiphenyl and the Two Isomeric 2-Alkylbicyclohexyl Series. By Irving A. Goodman and Paul H. Wise.
1066. Analysis of Temperature Distribution in Liquid-Cooled Turbine Blades. By John N. B. Livingood and W. Byron Brown.
1067. Generalization of Boundary-Layer Momentum-Integral Equations to Three-Dimensional Flows Including Those of Rotating System. By Artur Mager.
1068. Automatic Control Systems Satisfying Certain General Criterions on Transient Behavior. By Aaron S. Boksenbom and Richard Hood.
1069. On a Solution of the Nonlinear Differential Equation for Transonic Flow Past a Wave-Shaped Wall. By Carl Kaplan.
1070. Matrix Method of Determining the Longitudinal-Stability Coefficients and Frequency Response of an Aircraft From Transient Flight Data. By James J. Donegan and Henry A. Pearson.
1071. Theoretical Symmetric Span Loading Due to Flap Deflection for Wings of Arbitrary Plan Form at Subsonic Speeds. By John DeYoung.
1072. Inelastic Column Behavior. By John E. Duberg and Thomas W. Wilder III.
1073. An Iterative Transformation Procedure for Numerical Solution of Flutter and Similar Characteristic-Value Problems. By Myron L. Gossard.
1074. Hydrodynamic Impact of a System With a Single Elastic Mode. I—Theory and Generalized Solution With an Application to an Elastic Airframe. By Wilbur L. Mayo.

No.

1075. Hydrodynamic Impact of a System With a Single Elastic Mode. II—Comparison of Experimental Force and Response With Theory. By Robert W. Miller and Kenneth F. Merten.
1076. Effects on Longitudinal Stability and Control Characteristics of a Boeing B-29 Airplane of Variations in Stick-Force and Control-Rate Characteristics Obtained Through Use of a Booster in the Elevator-Control System. By Charles W. Mathews, Donald B. Talmage, and James B. Whitten.
1077. Two- and Three-Dimensional Unsteady Lift Problems in High-Speed Flight. By Harvard Lomax, Max. A. Heaslet, Franklyn B. Fuller, and Loma Sluder.
1078. Effects of Compressibility on the Performance of Two Full-Scale Helicopter Rotors. By Paul J. Carpenter.
1079. Sound from a Two-Blade Propeller at Supersonic Tip Speeds. By Harvey H. Hubbard and Leslie W. Lassiter.
1080. A Theoretical Analysis of the Effects of Fuel Motion on Airplane Dynamics. By Albert A. Schy.
1081. A Study of Second-Order Supersonic Flow Theory. By Milton D. Van Dyke.
1082. Method of Analysis for Compressible Flow Through Mixed-Flow Centrifugal Impellers of Arbitrary Design. By Joseph T. Hamrick, Ambrose Ginsburg, and Walter M. Osborn.
1083. Axisymmetric Supersonic Flow in Rotating Impellers. By Arthur W. Goldstein.
1084. Comparison of High-Speed Operating Characteristics of Size 215 Cylindrical-Roller Bearings as Determined in Turbojet Engine and in Laboratory Test Rig. By E. Fred Macks and Zolton N. Nemeth.
1085. Discussion of Boundary-Layer Characteristics Near the Wall of an Axial-Flow Compressor. By Artur Mager, John J. Mahoney, and Ray E. Budinger.
1086. Analysis of the Effects of Wing Interference on the Tail Contributions to the Rolling Derivatives. By William H. Michael, Jr.
1087. Internal-Liquid-Film-Cooling Experiments With Air-Stream Temperature to 2,000° F. in 2- and 4-Inch-Diameter Horizontal Tubes. By George R. Kinney, Andrew E. Abramson, and John L. Sloop.
1088. Theoretical Damping Roll and Rolling Moment Due to Differential Wing Incidence for Slender Cruciform Wings and Wing-Body Combinations. By Gaynor J. Adams and Duane W. Dugan.
1089. Single-Degree-of-Freedom-Flutter Calculations for a Wing in Subsonic Potential Flow and Comparison with an Experiment. By Harry L. Runyan.
1090. Method for Calculating Lift Distributions for Unswept Wings With Flaps or Ailerons by Use of Nonlinear Section Lift Data. By James C. Sivells and Gertrude C. Westrick.
1091. Effect of Aspect Ratio on the Low-Speed Lateral Control Characteristics of Untapered Low-Aspect-Ratio Wings Equipped With Flap and With Retractable Ailerons. By Jack Fischel, Rodger L. Naeseth, John R. Hagerman, and William M. O'Hare.

[1] The missing numbers in the series of Reports were released before or after the period covered by this report.

No.

1092. Flight Investigation of the Effect of Control Centering Springs on the Apparent Spiral Stability of a Personal-Owner Airplane. By John P. Campbell, Paul A. Hunter, Donald E. Hewes and James B. Whitten.

1093. Heat Transfer to Bodies in a High-Speed Rarefied-Gas Stream. By Jackson R. Stalder, Glen Goodwin, and Marcus O. Creager.

1094. An Experimental Investigation of Transonic Flow Past Two-Dimensional Wedge and Circular-Arc Sections Using a Mach-Zehnder Interferometer. By Arthur Earl Bryson, Jr.

1095. Transonic Flow Past a Wedge Profile With Detached Bow Wave. By Walter G. Vincenti and Cleo B. Wagoner.

1096. Experimental Determination of the Effect of Horizontal-Tail Size, Tail Length, and Vertical Location on Low-Speed Static Longitudinal Stability and Damping in Pitch of a Model Having 45° Sweptback Wing and Tail Surfaces. By Jacob Lichtenstein.

1097. Stresses in a Two-Bay Noncircular Cylinder Under Transverse Loads. By George E. Griffith.

1098. Summary of Methods for Calculating Dynamic Lateral Stability and Response and for Estimating Lateral Stability Derivatives. By John P. Campbell and Marion O. McKinney.

1099. Air Forces and Moments on Triangular and Related Wings With Subsonic Leading Edges Oscillating in Supersonic Potential Flow. By Charles E. Watkins and Julian H. Berman.

1100. On Reflection of Shock Waves From Boundary Layers. By H. W. Liepmann, A. Roshko, and S. Dhawan.

1101. Flight Investigation of a Mechanical Feel Device in an Irreversible Elevator Control System of a Large Airplane. By B. Porter Brown, Robert G. Chilton, and James B. Whitten.

1102. The Linearized Characteristics Method and Its Application to Practical Nonlinear Supersonic Problems. By Antonio Ferri.

1103. Generalized Theory for Seaplane Impact. By Benjamin Milwitzky.

1104. Preliminary Investigation of a New Type of Supersonic Inlet. By Antonio Ferri and Louis M. Nucci.

1105. Chordwise and Compressibility Corrections to Slender-Wing Theory. By Harvard Lomax and Loma Sluder.

1106. The Langley Annular Transonic Tunnel. By Louis W. Habel, James H. Henderson, and Mason F. Miller.

1107. An Empirically Derived Basis for Calculating the Area, Rate, and Distribution of Water-Drop Impingement on Airfoils. By Norman R. Bergrun.

1108. Experimental Aerodynamic Derivatives of a Sinusoidally Oscillating Airfoil in Two-Dimensional Flow. By Robert L. Halfman.

1109. Experimental Investigation of Base Pressure on Blunt-Trailing-Edge Wings at Supersonic Velocities. By Dean R. Chapman, William R. Wimbrow, and Robert H. Kester.

1110. Some Features of Artificially Thickened Fully Developed Turbulent Boundary Layers With Zero Pressure Gradient. By P. S. Klebanoff and Z. W. Diehl.

TECHNICAL NOTES [1]

2549. Investigation of Hydrocarbon Ignition. By Charles E. Frank and Angus U. Blackham.

[1] The missing numbers in the series of Technical Notes were released before or after the period covered by this report.

No.

2577. On the Angular Distribution of Slip Lines in Polycrystalline Aluminum Alloy. By John M. Hedgepeth, S. B. Batdorf, and J. Lyell Sanders, Jr.

2643. Span Load Distributions Resulting From Angle of Attack, Rolling, and Pitching for Tapered Sweptback Wings With Streamwise Tips. Supersonic Leading and Trailing Edges. By John C. Martin and Isabella Jeffreys.

2656. A Blade-Element Analysis for Lifting Rotors That Is Applicable for Large Inflow and Blade Angles and any Reasonable Blade Geometry. By Walter Castles, Jr. and Noah C. New.

2661. A Summary of Diagonal Tension. Part I—Methods of Analysis. By Paul Kuhn, James P. Peterson, and L. Ross Levin.

2675. Measurements of Flying Qualities of an F-47D-30 Airplane to Determine Lateral and Directional Stability and Control Characteristics. By R. Fabian Goranson and Christopher C. Kraft, Jr.

2694. A Method for Stabilizing Shock Waves in Channel Flow by Means of a Surge Chamber. By Stanford E. Neice.

2698. Theoretical Analysis of Hydrodynamic Impact of a Prismatic Float Having Freedom in Trim. By Robert W. Miller.

2720. Effects of Aspect Ratio on Air Flow at High Subsonic Mach Numbers. By W. F. Lindsey and Milton D. Humphreys.

2727. Experiments in External Noise Reduction of a Small Pusher-Type Amphibian Airplane. By John P. Roberts and Leo L. Beranek.

2730. Choking of a Subsonic Induction Tunnel by the Flow From an Induction Nozzle. By W. F. Lindsey.

2735. An Analysis of the Normal Accelerations and Airspeeds of a Two-Engine Type of Transport Airplane in Commercial Operations on Routes in the Central United States from 1948 to 1950. By Walter G. Walker and Paul W. J. Schumacher.

2737. Plastic Stress-Strain Relations for Combined Tension and Compression. By Joseph Marin and H. A. B. Wiseman.

2739. Numerical Determination of Indicial Lift and Moment Functions for a Two-Dimensional Sinking and Pitching Airfoil at Mach Numbers 0.5 and 0.6. By Bernard Mazelsky and Joseph A. Drischler.

2741. Investigation of the Influence of Fuselage and Tail Surfaces on Low-speed Static Stability and Rolling Characteristics of a Swept-Wing Model. By John D. Bird, Jacob H. Lichtenstein, and Byron M. Jaquet.

2742. Boundary-Layer Development and Skin Friction at Mach Number 3.05. By Paul F. Brinich and Nick S. Diaconis.

2743. Landing-Gear Impact. By W. Flügge.

2745. Influence of Chemical Composition on Rupture Test Properties at 1,500° F. of Forged Chromium-Cobalt-Nickel-Iron Base Alloys. By J. W. Freeman, J. F. Ewing, and A. E. White.

2746. Preview of Behavior of Grain Boundaries in Creep of Aluminum Bicrystals. By F. N. Rhines and A. W. Cochardt.

2747. Charts and Approximate Formulas for the Estimation of Aeroelastic Effects on the Lateral Control of Swept and Unswept Wings. By Kenneth A. Foss and Franklin W. Diederich.

2751. A Simple Approximate Method for Calculating Spanwise Lift Distributions and Aerodynamic Influence Coefficients at Subsonic Speeds. By Franklin W. Diederich.

No.

2753. Effects of Mach Number Variation Between 0.07 and 0.34 and Reynolds Number Variation between 0.97 x 10^6 and 8.10 x 10^6 on the Maximum Lift Coefficient of a Wing of NACA 64–210 Airfoil Sections. By James E. Fitzpatrick and William C. Schneider.

2755. Analysis of Landing-Gear Behavior. By Benjamin Milwitzky and Francis E. Cook.

2762. Aerodynamic Characteristics of Three Deep-Step Planing-Tail Flying-Boat Hulls and a Transverse-Step Hull with Extended Afterbody. John M. Riebe and Rodger L. Naeseth.

2763. Gust-Response Analysis of an Airplane Including Wing Bending Flexibility. By John C. Houbolt and Eldon E. Kordes.

2764. Accuracy of Approximate Methods for Predicting Pressures on Pointed Nonlifting Bodies of Revolution in Supersonic Flow. By Dorris M. Ehret.

2765. A Flight Investigation of the Effect of Shape and Thickness of the Boundary Layer on the Pressure Distribution in the Presence of Shock. By Eziaslav N. Harrin.

2766. Some Effects of Amplitude and Frequency on the Aerodynamic Damping of a Model Oscillating Continuously in Yaw. By Lewis R. Fisher and Walter D. Wolhart.

2767. Dynamics of Mechanical Feedback-Type Hydraulic Servomotors Under Inertia Load. By Harold Gold, Edward W. Otto, and Victor L. Ransom.

2768. Supersonic Flow With Whirl and Vorticity in Axisymmetric Channels. By Ralph J. Eschborn.

2769. Experimental and Theoretical Determination of Thermal Stresses in a Flat Plate. By Richard R. Heldenfels and William M. Roberts.

2770. Study of the Pressure Rise Across Shock Waves Required to Separate Laminar and Turbulent Boundary Layers. By Coleman duP. Donaldson and Roy H. Lange.

2771. Thermal Buckling of Plates. By Myron L. Gossard, Paul Seide, and William M. Roberts.

2772. Driving Standing Waves by Heat Addition. By Perry L. Blackshear, Jr.

2773. An Approximate Method for Determining the Displacement Effects and Viscous Drag of Laminar Boundary Layers in Two-Dimensional Hypersonic Flow. By Mitchel H. Bertram.

2774. A Method for Finding a Least-Squares Polynomial That Passes Through a Specified Point With Specified Derivatives. By Neal Tetervin.

2775. Effect of Linear Spanwise Variations of Twist and Circular-Arc Camber on Low-Speed Static Stability, Rolling, and Yawing Characteristics of a 45° Sweptback Wing of Aspect Ratio 4 and Taper Ratio 0.6. By Byron M. Jaquet.

2776. The Effect of a Simulated Propeller Slipstream on the Aerodynamic Characteristics of an Unswept Wing Panel With and Without Nacelles at Mach Numbers from 0.30 to 0.86. By Gareth H. Jordan and Richard I. Cole.

2777. Theoretical Distribution of Slip Angles in an Aggregate of Face-Centered Cubic Crystals. By John M. Hedgepeth.

2780. Flight Investigation of Transient Wing Response on a Four-Engine Bomber Airplane in Rough Air With Respect to Center-of-Gravity Accelerations. By Harry C. Mickleboro, Richard B. Fahrer, and C. C. Shufflebarger.

2781. The Effects on Dynamic Lateral Stability and Control of Large Artificial Variations in the Rotary Stability Derivatives. By Robert O. Schade and James L. Hassell, Jr.

No.

2784. Method for Calculation of Compressible Laminar Boundary-Layer Characteristics in Axial Pressure Gradient With Zero Heat Transfer. By Morris Morduchow and Joseph H. Clarke.

2785. Introduction to Electrical-Circuit Analogies for Beam Analysis. By Stanley U. Benscoter and Richard H. MacNeal.

2786. Equivalent Plate Theory for a Straight Multicell Wing. By Stanley U. Benscoter and Richard H. MacNeal.

2787. Airfoil Profiles for Minimum Pressure Drag at Supersonic Velocities-Application of Shock-Expansion Theory, Including Consideration of Hypersonic Range. By Dean R. Chapman.

2788. Effects of Solvents in Improving Boundary Lubrication of Steel by Silicones. By S. F. Murray and Robert L. Johnson.

2789. Some Dynamic Effects of Fuel Motion in Simplified Model Tip Tanks on Suddenly Excited Bending Oscillations. By Kenneth F. Merten and Bertrand H. Stephenson.

2790. Flow Studies in the Vicinity of a Modified Flat-Plate Rectangular Wing of Aspect Ratio 0.25. By William H. Michael, Jr.

2791. Correlation of Tensile Strength, Tensile Ductility, and Notch Tensile Strength With the Strength of Rotating Disks of Several Designs in the Range of Low and Intermediate Ductility. By Arthur G. Holms and Andrew J. Repko.

2792. Direct-Reading Design Charts for 24S–T3 Aluminum-Alloy Flat Compression Panels Having Longitudinal Formed Hat-Section Stiffeners and Comparisons With Panels Having Z-Section Stiffeners. By William A. Hickman and Norris F. Dow.

2793. A Method for the Determination of the Time Lag in Pressure Measuring Systems Incorporating Capillaries. By Archibald R. Sinclair and A. Warner Robins.

2794. A Comparison of Two Methods of Linearized Characteristics for a Simple Unsteady Flow. By Roger D. Sullivan.

2795. Effects of Wing Sweep on the Upwash at the Propeller Planes of Multiengine Airplanes. By Vernon L. Rogallo.

2796 Experimental Study of the Effects of Finite Surface Disturbances and Angle of Attack on the Laminar Boundary Layer of an NACA 64A010 Airfoil With Area Suction. By Milton A. Schwartzberg and Albert L. Braslow.

2797. A Study of the Transient Behavior of Shock Waves in Transonic Channel Flows. By Robert V. Hess.

2798. An Experimental Investigation of the Behavior of 24S–T4 Aluminum Alloy Subjected to Repeated Stresses of Constant and Varying Amplitudes. By Herbert F. Hardrath and Elmer C. Utley, Jr.

2799. Simple Graphical Solution of Heat Transfer and Evaporation From Surface Heated to Prevent Icing. By Vernon H. Gray.

2800. Solutions of Laminar-Boundary-Layer Equations Which Result in Specific-Weight-Flow Profiles Locally Exceeding Free-Stream Values. By W. Byron Brown and John N. B. Livingood.

2801. Investigation With an Interferometer of the Flow Around a Circular-Arc Airfoil at Mach Numbers Between 0.6 and 0.9. By George P. Wood and Paul B. Gooderum.

2802. Bonding of Molybdenum Disulfide to Various Materials to Form a Solid Lubricating Film. II—Friction and Endurance Characteristics of Films Bonded by Practical Methods. By Douglas Godfrey and Edmond E. Bisson.

No.

2843. Auxiliary Equipment and Techniques for Adapting the Constant-Temperature Hot-Wire Anemometer to Specific Problems in Air-Flow Measurements. By James C. Laurence and L. Gene Landes.

2844. Laminar Boundary Layer on Cone in Supersonic Flow at Large Angle of Attack. By Franklin K. Moore.

2845. X-ray Instrumentation for Density Measurements in a Supersonic Flow Field. By John Dimeff, Ralph K. Hallett, Jr., and C. Frederick Hansen.

2846. Effective Lubrication Range for Steel Surfaces Boundary Lubricated at High Sliding Velocities by Various Classes of Synthetic Fluids. By Robert L. Johnson, Max A. Swikert, and Edmond E. Bisson.

2847. Section Characteristics of a 10.5-Percent-Thick Airfoil With Area Suction as Affected by Chordwise Distribution of Permeability. By Robert E. Dannenberg and James A. Weiberg.

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Part II—COMMITTEE ORGANIZATION AND MEMBERSHIP

The National Advisory Committee for Aeronautics was established by Act of Congress approved March 3, 1915 (U. S. Code Supplement IV, title 50, sec. 151). The membership, appointed by the President, includes two representatives each of the Department of the Air Force, the Department of the Navy, and the Civil Aeronautics Authority, and one representative each of the Smithsonian Institution, the United States Weather Bureau, and the National Bureau of Standards. In addition seven members are appointed for five-year terms from persons "acquainted with the needs of aeronautical science, either civil or military, or skilled in aeronautical engineering or its allied sciences." The representatives of the Government organizations serve for indefinite periods, and all members serve as such without compensation.

The following changes in the membership of the Committee have taken place during the past year:

Honorable Joseph P. Adams, member of the Civil Aeronautics Board, was appointed a member of the Committee on November 21, 1952, succeeding Honorable Donald W. Nyrop, who resigned as chairman of the CAB and member of the NACA October 31, 1952.

On January 14, 1953, Dr. Leonard Carmichael, newly appointed secretary of the Smithsonian Institution, was named a member of the NACA to succeed Dr. Alexander Wetmore, his predecessor as secretary of the Smithsonian, who retired December 31, 1952. Dr. Wetmore was succeeded as vice chairman of the NACA by Dr. Detlev W. Bronk, who was elected to that office on January 23, 1953.

Vice Admiral Ralph A. Ofstie, USN, Deputy Chief of Naval Operations (Air), was appointed a member of the Committee March 30, 1953, succeeding Vice Admiral Matthias B. Gardner, who had just been detached from the same Navy post and assigned to other duty.

On July 8, 1953, the President appointed Rear Admiral Lloyd Harrison, USN, Deputy and Assistant Chief of the Bureau of Aeronautics, a member of the NACA succeeding Vice Admiral (then Rear Admiral) Thomas S. Combs, who was detached June 26 as Chief of the Bureau of Aeronautics and assigned to sea duty.

Honorable Robert B. Murray, Jr., Under Secretary of Commerce for Transportation, was appointed to the NACA on July 10, 1953, as successor to Honorable Thomas W. S. Davis, who resigned as Assistant Secretary of Commerce and NACA member January 20, 1953.

The abolition of the Research and Development Board, effective June 30, 1953, in accordance with Reorganization Plan No. 6, resulted in the termination of the membership on the NACA of Honorable Walter G. Whitman, who had been serving as chairman of that Board.[1]

In accordance with the regulations of the Committee as approved by the President, the chairman and vice chairman and the chairman and vice chairman of the executive committee are elected annually.

On October 23, 1953, Dr. Jerome C. Hunsaker was reelected chairman of the NACA and of the executive committee, Dr. Detlev W. Bronk, vice chairman of the NACA, and Dr. Francis W. Reichelderfer, vice chairman of the executive committee.

The Committee membership is as follows:

- Dr. Jerome C. Hunsaker, Massachusetts Institute of Technology, Chairman.
- Dr. Detlev W. Bronk, President, Rockefeller Institute for Medical Research, Vice Chairman.
- Honorable Joseph P. Adams, member, Civil Aeronautics Board.
- Dr. Allen V. Astin, Director, National Bureau of Standards.
- Dr. Leonard Carmichael, Secretary, Smithsonian Institution.
- Lieutenant General Laurence C. Craigie, USAF, Deputy Chief of Staff, Development.
- Dr. James H. Doolittle, Vice President, Shell Oil Company.
- Rear Admiral Lloyd Harrison, USN, Deputy and Assistant Chief of the Bureau of Aeronautics.
- Mr. Ronald M. Hazen, Director of Engineering, Allison Division, General Motors Corporation.
- Mr. William Littlewood, Vice President, Engineering, American Airlines, Inc.
- Honorable Robert B. Murray, Jr., Under Secretary of Commerce for Transportation.
- Vice Admiral Ralph A. Ofstie, USN, Deputy Chief of Naval Operations (Air).
- Lieutenant General Donald L. Putt, USAF, Commander, Air Research and Development Command.
- Dr. Arthur E. Raymond, Vice President, Engineering, Douglas Aircraft Company, Inc.
- Dr. Francis W. Reichelderfer, Chief, U. S. Weather Bureau.
- Dr. Theodore P. Wright, Vice President for Research, Cornell University.

Assisting the Committee in its coordination of aeronautical research and the formulation of its research programs are four technical committees: Aerodynamics, Power Plants for Aircraft, Aircraft Construction, and Operating Problems. Each of these committees is aided by from four to eight technical subcommittees. The Committee is advised on matters of policy affecting the aircraft industry by an Industry Consulting Committee.

Membership of the committees, with the subcommittees listed under the technical committees having cognizance, is as follows:

COMMITTEE ON AERODYNAMICS

Dr. Theodore P. Wright, Cornell University, Chairman.
Capt. Walter S. Diehl, U. S. N. (Ret.), Vice Chairman.
Dr. Albert E. Lombard, Jr., Directorate of Research and Development, U. S. Air Force.
Col. Robert G. Ruegg, U. S. A. F., Wright Air Development Center.
Mr. F. A. Louden, Bureau of Aeronautics, Department of the Navy.
Capt. M. R. Kelley, U. S. N. (Ret.), Bureau of Ordnance.
Maj. Gen. Leslie E. Simon, U. S. A., Chief, Ordnance Research and Development Division.
Mr. Harold D. Hoekstra, Civil Aeronautics Administration.
Dr. Hugh L. Dryden (ex officio).
Mr. Floyd L. Thompson, NACA Langley Aeronautical Laboratory.
Mr. Russell G. Robinson, NACA Ames Aeronautical Laboratory.
Prof. Emerson W. Conlon, Fairchild Engine and Airplane Corp.
Mr. Alexander H. Flax, Cornell Aeronautical Laboratory, Inc.
Mr. Edward J. Horkey, Pastushin Aviation Corp.
Mr. Clarence L. Johnson, Lockheed Aircraft Corp.
Dr. Clark B. Millikan, California Institute of Technology.
Dr. W. Bailey Oswald, Douglas Aircraft Co., Inc.
Dr. Allen E. Puckett, Hughes Aircraft Co.
Mr. George S. Schairer, Boeing Airplane Co.
Mr. E. G. Stout, Consolidated Vultee Aircraft Corp.
Prof. E. S. Taylor, Massachusetts Institute of Technology.
Mr. R. H. Widmer, Consolidated Vultee Aircraft Corp.
Mr. Robert J. Woods, Bell Aircraft Corp.

Mr. Milton B. Ames, Jr., Secretary

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Dr. Theodore Theodorsen, Air Research and Development Command, U. S. Air Force.
Major Michael Zubon, U. S. A. F., Air Research and Development Command.
Mr. Phillip Eisenberg, Office of Naval Research, Department of the Navy.
Comdr. L. G. Pooler, U. S. N., Bureau of Ordnance.
Mr. Joseph Sternberg, Ballistic Research Laboratories, Aberdeen Proving Ground.
Dr. G. B. Schubauer, National Bureau of Standards.
Dr. Carl Kaplan, NACA Langley Aeronautical Laboratory.
Mr. John Stack, NACA Langley Aeronautical Laboratory.
Mr. Robert T. Jones, NACA Ames Aeronautical Laboratory.
Mr. Walter G. Vincenti, NACA Ames Aeronautical Laboratory.
Dr. John C. Evvard, NACA Lewis Flight Propulsion Laboratory.
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Dr. William R. Sears, Cornell University.

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Dr. H. H. Kurzweg, Naval Ordnance Laboratory.
Mr. C. L. Poor III, Ballistic Research Laboratories, Aberdeen Proving Ground.
Mr. Robert R. Gilruth, NACA Langley Aeronautical Laboratory.
Mr. John Stack, NACA Langley Aeronautical Laboratory.
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Mr. F. B. Gustafson, NACA Langley Aeronautical Laboratory.
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Mr. Stephen H. Rolle, Civil Aeronautics Administration.
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Mr. Abe Silverstein, NACA Lewis Flight Propulsion Laboratory.
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Part III—FINANCIAL REPORT

Appropriations for the fiscal year 1953.—Funds in the following amounts were appropriated for the Committee for the fiscal year 1953 in the Independent Offices Appropriation Act, 1953, approved July 5, 1952:

Salaries and expenses		$48,586,100
Construction and equipment of laboratory facilities:		
Funds to continue financing of the fiscal year 1951 program:		
Langley Aeronautical Laboratory	$516,324	
Ames Aeronautical Laboratory	483,676	
		1,000,000
Funds to completely finance the fiscal year 1953 program:		
Langley Aeronautical Laboratory	11,115,000	
Lewis Flight Propulsion Laboratory	5,585,000	
		16,700,000
Total appropriated funds, fiscal year 1953		66,286,100

Obligations incurred against the fiscal year 1953 appropriated funds are listed below, together with the unobligated balances remaining on June 30, 1953. The figures shown for salaries and expenses include the costs for personal services, travel, transportation, communication, utility services, printing and reproduction, contractual services, supplies, equipment, and taxes and assessments.

Salaries and expenses:		
NACA Headquarters		$1,185,835
Langley Aeronautical Laboratory		19,218,601
Pilotless Aircraft Station		593,496
High-Speed Flight Station		1,368,065
Ames Aeronautical Laboratory		7,782,541
Western Coordination Office		17,339
Lewis Flight Propulsion Laboratory		17,276,417
Wright-Patterson Coordination Office		12,346
Research contracts—educational institutions		739,543
Services performed by National Bureau of Standards and Forest Products Laboratory		204,800
Unobligated balance		187,117
		48,586,100
Construction and equipment of laboratory facilities:		
Funds to continue financing of the fiscal year 1951 program:		
Langley Aeronautical Laboratory	$512,325	
Ames Aeronautical Laboratory	483,676	
Unobligated balance	3,999	
		1,000,000
Funds to completely finance the fiscal year 1953 program:		
Langley Aeronautical Laboratory	$1,817,214	
Lewis Flight Propulsion Laboratory	4,536,230	
Construction and equipment of laboratory facilities—Continued		
Funds to completely finance the fiscal year 1953 program—Con.		
Reserve for transfer to the fiscal year 1954 program	$1,450,000	
Reserve for transfer to the fiscal year 1955 program	70,000	
Unobligated balance	[1] 8,826,556	
		$16,700,000
Total appropriated funds, fiscal year 1953		66,286,100

[1] This unobligated balance remains available for obligation until expended.

Appropriation for the Unitary Wind Tunnel Plan Act.—Funds in the amount of $75,000,000 were appropriated in the Deficiency Appropriation Act, 1950, approved June 29, 1950, for the construction of wind tunnels authorized in the Unitary Wind Tunnel Plan Act of 1949 (Public Law 415, 81st Congress, approved October 27, 1949). These funds are available until expended. Allotments and obligations as of June 30, 1953, are as follows:

	Allotments	*Obligations as of June 30, 1953*
Langley Aeronautical Laboratory	$15,150,000	$14,625,966
Ames Aeronautical Laboratory	26,994,000	25,953,021
Lewis Flight Propulsion Laboratory	32,856,000	28,448,991
Total	75,000,000	69,027,978

Appropriations for the fiscal year 1954.—The major allotments of the funds appropriated for the Committee for the fiscal year 1954 in the First Independent Offices Appropriation Act, 1954, approved July 31, 1953, are as follows:

Salaries and expenses		$50,000,000
Budget reserve		1,000,000
Construction and equipment of laboratory facilities:		
Funds to complete financing of the fiscal year 1951 program:		
Langley Aeronautical Laboratory	$550,000	
Ames Aeronautical Laboratory	3,650,000	
		4,200,000
Funds to finance the fiscal year 1954 program:		
Langley Aeronautical Laboratory	[2] 3,939,200	
Ames Aeronautical Laboratory	990,700	
Lewis Flight Propulsion Laboratory	10	
Budget reserve	1,999,090	
Reserve for transfer to the fiscal year 1955 program	310,000	
		7,239,000
Total appropriated funds, fiscal year 1954		62,439,000

[2] The fiscal year 1953 reserve of $1,450,000 for transfer to the fiscal year 1954 program will be used to complete the financing of the Langley fiscal year 1954 projects.